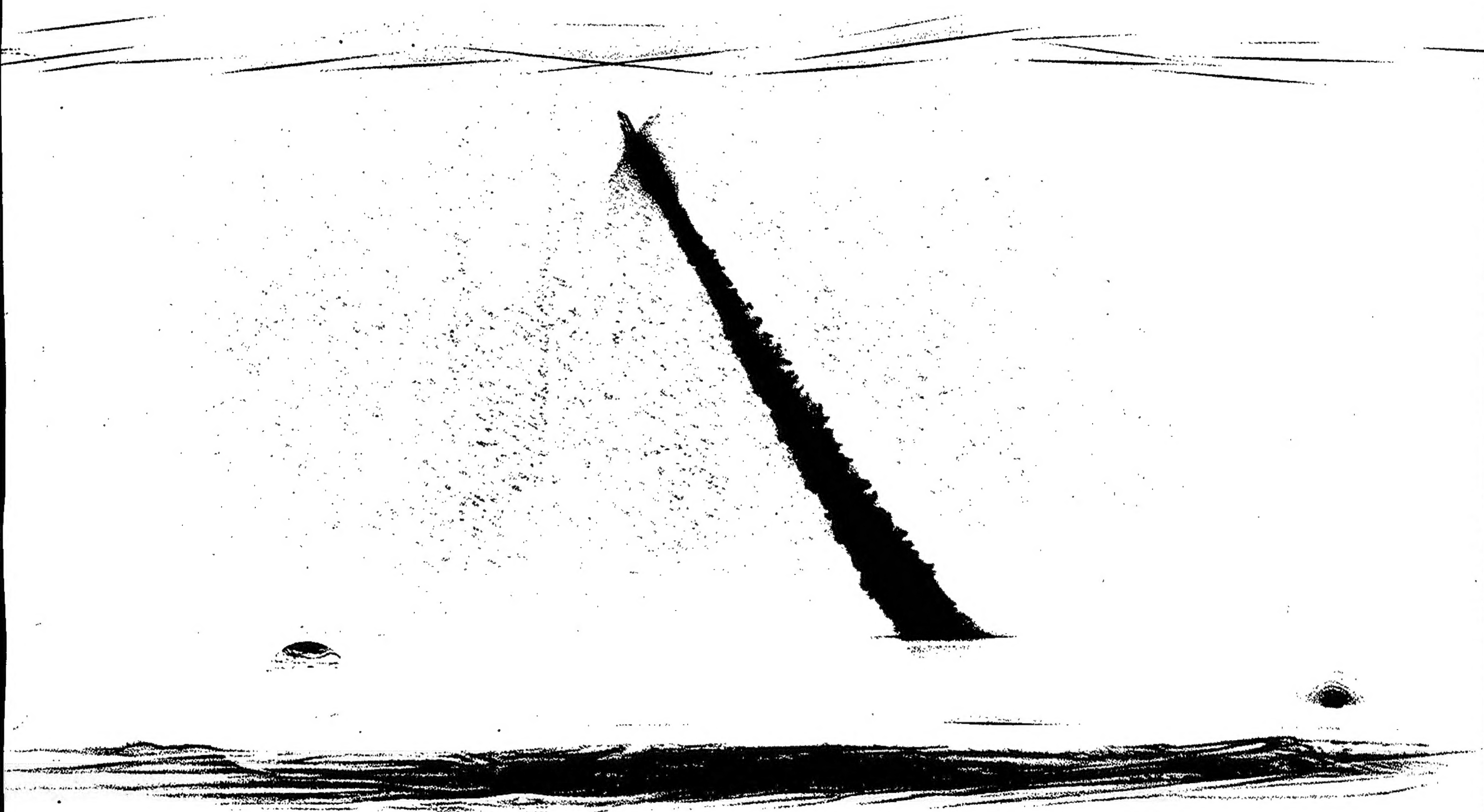
OAST
Technology For the Future

Volume III—Critical Technologies, Themes 5–8



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IN-SPACE TECHNOLOGY EXP

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IN-STEP 88 WORKSHOP

FOREWORD

At the workshop, Dr. Harrison H. Schmitt emphasized that the nations which effectively exploit the advantages of space will lead human activities on earth. The major space goal of the National Aeronautics and Space Administration's Office of Aeronautics and Space Technology (OAST) is to provide enabling technologies, validated at a level suitable for user-readiness, for future space missions in order to ensure continued U.S. Leadership in space. An important element in accomplishing this goal is the In-Space Technology Experiments Program whose purpose is to explore and validate in space advanced technologies that will improve the effectiveness and efficiency of current and future space systems. OAST has worked closely with the aerospace community over the last few years to utilize the Space Shuttle, expendable launch vehicles, and, in the future, the Space Station Freedom for experimentation in space in the same way that we utilize wind tunnels to develop aeronautical technologies. This close cooperation with the user community is an important, integral part of the evolution of the In-Space Technology Experiments Program which was originated to provide access to space for technology research and experimentation for the entire U.S. aerospace community.

On December 6 through 9, 1988, almost 400 researchers, technologists, and managers from U.S. companies, universities, and the government participated in the OAST IN-STEP 88 Workshop. The participants reviewed the current in-space technology flight experiments, identified and prioritized the technologies that are critical for future national space programs and that require verification or validation in space, and provided constructive feedback on the future plans for the In-Space Technology Experiments Program. The attendees actively participated in the identification and prioritization of future critical space technologies in eight major discipline theme areas. These critical space technologies will help focus future solicitations for in-space flight experiments. The material within these four volumes is the culmination of the workshop participants' efforts to review the planning for the future of this program.

Dr. Leonard Harris
Chief Engineer
Office of Aeronautics and
Space Technology, NASA

OAST IN-STEP 88 WORKSHOP
Critical Technologies (Themes 5-8)

VOLUME III

INTRODUCTION TO VOLUME III

NASA's Office of Aeronautics and Space Technology (OAST) conducted a workshop on the In-Space Technology Experiments Program (IN-STEP) December 6-9, 1988, in Atlanta, Georgia. The purpose of this workshop was to identify and prioritize space technologies which are critical for future national space programs and which require validation in the space environment. A secondary objective was to review the current NASA (In-Reach) and Industry/University (Out-Reach) experiments. Finally, the aerospace community was requested to review and comment on the proposed plans for the continuation of the In-Space Technology Experiments Program. In particular, the review included the proposed process for focusing the next experiment selection on specific, critical technologies and the process for implementing the hardware development and integration on the Space Shuttle vehicle. The product of the workshop was a prioritized listing of the critical space technology needs in each of eight technology disciplines. These listings were the cumulative recommendations of nearly 400 participants, which included researchers, technologists, and managers from aerospace industries, universities, and government organizations.

The identification and prioritization of the critical space technology needs were initiated by assigning NASA chairpersons (theme leaders) to the eight major technology disciplines or themes requiring consideration. These themes were as follows:

- space structures
- space environmental effects
- power systems and thermal management
- fluid management and propulsion systems
- automation and robotics
- sensors and information systems
- in-space systems
- humans in space

In order to provide further structure within each theme, the chairpersons divided their themes into three theme elements each. The theme element concept allowed focused technical discussions to occur within the broad discipline themes. For each theme element, the theme leader selected government, industry, and university experts to present the critical space technology needs of their respective organizations. The presentations were reviewed and discussed by the theme audiences (other members of the aerospace community), and prioritized lists of the critical technologies which require verification and validation in space were established for each theme element. The comments and conclusions for each theme were incorporated into a summary listing of the critical space technology needs and associated flight experiments representing the combined inputs of the speakers, the audience, and the theme leader.

The critical space technology needs and associated space flight experiments identified by the participants provide an important part of the strategic planning process for space technology development and provide the basis for the next solicitation for space technology flight experiments. The results of the workshop will be presented to the IN-STEP Selection Advisory Committee in early 1989. This committee will review the critical technology needs, the funding available for the program, and the space flight opportunities available to determine the specific technologies for which space flight experiments will be requested in the next solicitation .

These proceedings are organized into an Executive Summary and four volumes: Executive Summary; In-Reach/Out-Reach Experiments and Experiment Integration Process (Volume I); and Critical Technology Presentations (Volumes II and III).

Volume III contains the theme introduction given by the chairperson, the critical technology presentations for each theme element, and the summary listings of critical space technology needs for each theme. The introduction for each theme includes the chairperson's overview of the theme and its theme elements, along with instructions for the participants. The critical technology presentations are as described above, and the summaries are the listings of critical space technology needs and associated flight experiments as discussed above. This volume contains the documentation for the following four themes: automation and robotics, sensors and information systems, in-space systems, and humans in space.

PRESENTATION OF CRITICAL TECHNOLOGIES FOR THEMES 5-8

5. AUTOMATION AND ROBOTICS

AUTOMATION AND ROBOTICS BACKGROUND AND OBJECTIVES

ANTAL K. BEJCZY
JET PROPULSION LABORATORY

ORGANIZATION

THEME LEADER: ANTAL K. BEJCZY, JPL

COMMITTEE:
THOMAS S. DOLLMAN, MSFC
HENRY LUM, ARC
ALFRED J. MEINTEL, JR., LaRC
CHARLES R. PRICE, JSC
LLOYD R. PURVES, GSFC
DOUGLAS A. ROHN, LeRC
JAMES P. JENKINS, NASA HQ, OAST/RC (EX OFFICIO)

SUBTHEMES & THEME GROUPS:
1. ROBOTICS
2. TELEOPERATION
3. ARTIFICIAL INTELLIGENCE

THEME SESSION OBJECTIVES

PURPOSE

- IDENTIFY & PRIORITIZE IN-SPACE TECHNOLOGIES FOR AUTOMATION & ROBOTICS, BY CONSIDERING SUBTHEME DETAILS, WHICH
  - ARE CRITICAL FOR FUTURE U.S. SPACE PROGRAMS
  - REQUIRE DEVELOPMENT & IN-SPACE VALIDATION
- GENERATE COMMENTS AND SUGGESTIONS FROM AEROSPACE COMMUNITY ON OAST IN-STEP PLANS

PRODUCT

- PRIORITY LISTING OF CRITICAL SPACE TECHNOLOGY NEEDS & ASSOCIATED SPACE FLIGHT EXPERIMENTS, RECOMMENDED BY AEROSPACE COMMUNITY

THEME DESCRIPTION

- **SCOPE**

  FULL SPECTRUM OF TELEOPERATION, ROBOTICS AND ARTIFICIAL INTELLIGENCE COMPONENTS, SUBSYSTEMS AND SYSTEMS AS THEY RELATE TO SPACE MISSIONS, INCLUDING HUMAN OPERATOR FUNCTIONS IN THESE SYSTEMS

- **GOAL**

  PROVIDE THE TECHNOLOGY AND UNDERSTANDING OF ALL THREE SUBTHEMES NEEDED TO ENSURE PRODUCTIVE AND SAFE APPLICATION OF INCREASINGLY AUTOMATED ROBOTIC AND SYSTEM CAPABILITIES IN SPACE MISSIONS UNDER REMOTE HUMAN OPERATOR SUPERVISION, INCLUDING THE UNDERSTANDING OF HUMAN PERFORMANCE CAPABILITIES IN THESE SYSTEMS

DESCRIPTION OF SUBTHEME 1: ROBOTICS

TECHNOLOGY ELEMENTS

- ROBOT MECHANISMS AND ACTUATORS
- ROBOT SENSING
- ROBOT CONTROLS
- ROBOT PROCESSING AND ITS ARCHITECTURE
- ROBOT SYSTEM CONCEPTS AND DESIGNS

INCLUDING REDUNDANCY IN ROBOTIC SYSTEMS, TOGETHER WITH RELIABILITY AND FAULT TOLERANCE REQUIREMENTS IN SPACE SYSTEMS

SUBTHEME OBJECTIVES

DEVELOP A VALIDATED TECHNOLOGY BASE FOR ABOVE ELEMENTS, TAKING INTO ACCOUNT SPACE APPLICATION AND SPACE ENVIRONMENTAL CONDITIONS AND MISSION CONSTRAINTS

DESCRIPTION OF SUBTHEME 2: TELEOPERATION

TECHNOLOGY ELEMENTS

- MULTI-MODE OPERATOR INTERFACES TO TELEROBOTS
- INTELLIGENT DISPLAYS
- HIERARCHICAL CONTROL/INFORMATION ARCHITECTURES
- VISUAL PERCEPTION SYSTEMS
- COMMUNICATION TIME DELAY

INCLUDING SUPERVISORY COMMAND LANGUAGES, TRADED/SHARED MANUAL/COMPUTER CONTROLS AND THE USE OF EXPERT SYSTEMS BY HUMAN OPERATORS

SUBTHEME OBJECTIVES

DEVELOP A VALIDATED TECHNOLOGY BASE FOR EFFICIENT AND SAFE UTILIZATION OF HUMAN OPERATOR CAPABILITIES IN DIRECT OR SUPERVISORY CONTROL OF TELEROBOTS, TAKING INTO ACCOUNT THE EFFECTS OF SPACE CONDITIONS (MICROGRAVITY, ETC.) AND COMMUNICATION TIME DELAYS ON OPERATOR BEHAVIOR AND PERFORMANCE, AND ALSO CONSIDERING THE HANDLING OF SINGULAR OR UNEXPECTED TASKS

DESCRIPTION OF SUBTHEME 3: ARTIFICIAL INTELLIGENCE

TECHNOLOGY ELEMENTS

- OPERATIONS AND CONTROL PLANNING/COORDINATION
- PERFORMANCE MONITORING OF COMPLEX SYSTEMS
- ERROR DETECTION AND RECOVERY
- MULTI-SENSOR DATA INTERPRETATION
- OPERATOR INTERACTION WITH EXPERT SYSTEMS

USING EXISTING AND EVOLVING CAPABILITIES OF ARTIFICIAL OR MACHINE INTELLIGENCE TECHNIQUES

SUBTHEME OBJECTIVES

DEVELOP A VALIDATED TECHNOLOGY BASE FOR INCREASED LEVEL OF INTELLIGENT AUTOMATION APPLICABLE TO SPACE MISSIONS AND OPERATIONS, INCLUDING TELEROBOTIC MISSIONS AND OPERATIONS, TAKING INTO ACCOUNT SPACE OPERATIONS CONSTRAINTS

BACKGROUND OF THEME TECHNOLOGY DEVELOPMENT

- **SUMMARY OF A&R THEME FROM 1985 WILLIAMSBURG, VA WORKSHOP (SEE APPENDIX)**

- **ACCOMPLISHMENTS SINCE 1985**
  - IN-REACH ACTIVITIES
  - OUT-REACH ACTIVITIES
  - EXPERIMENTS IN PREPARATIONS
    - SHUTTLE RMS FTS/DEXTROUS MANIPULATION
    - TRIIFEX/ROTEX
    - S/S FTS

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THEME SESSION AGENDA

Time	Session	SPEAKERS & PANEL
9:45 A.M. → 11:45 A.M.	**SUBTHEME: ROBOTICS** SPEAKER 1. (30 min) SPEAKER 2. (30 min) SPEAKER 3. (30 min) DISCUSSION (30 min)	1. A. MEINTEL, LARC 2. T. DEPKOVICH/J. SPOFFORD, MARTIN MARIETTA SPACE SYSTEMS 3. PROFESSOR D. TESAR, UNIVERSITY OF TEXAS, AUSTIN PANEL: SUBTHEME SPEAKERS AND: PROFESSOR J. DUFFY, UNIV. OF FLORIDA; PROFESSOR G.SARIDIS, RPI; F. GARCIA, IBM; S. HARRIS, ODETICS.
1.00 P.M. → 3:00 P.M.	**SUBTHEME: TELEOPERATION** SPEAKER 1. (30 min) SPEAKER 2. (30 min) SPEAKER 3. (30 min) DISCUSSION (30 min)	1. C. PRICE, JSC 2. P. PIERSON, GENERAL ELECTRIC 3. PROFESSOR T. SHERIDAN, MIT PANEL: SUBTHEME SPEAKERS AND: L. JENKINS, JSC; PROFESSOR L. STARK, UC BERKELEY; PROFESSOR J. STAUDHAMMER, UNIVERSITY OF FLORIDA.
3:15 P.M. → 5:15 P.M.	**SUBTHEME: ARTIFICIAL INTELLIGENCE** SPEAKER 1. (30 min) SPEAKER 2. (30 min) SPEAKER 3. (30 min) DISCUSSION (30 min)	1. N. SLIWA/P. FRIEDLAND, ARC 2. D. ROSENBERG ISX, INC. 3. PROF. R. CANNON, STANFORD UNIV. PANEL: SUBTHEME SPEAKERS AND: R. SIMPSON, DARPA; J. DICKERSON, MCDONNEL-DOUGLAS SPACE DIV.

THEME DISCUSSIONS

- **<u>AFTER EACH SUBTHEME SESSION</u>**
  - OPEN 30 min DISCUSSION WITH AUDIENCE & THEME LEADER/SPEAKERS/PANEL
    - QUESTIONS & ANSWERS
    - IDENTIFICATION OF ADDITIONAL TECHNOLOGIES FROM AUDIENCE
  - AUDIENCE PRIORITIZATION OF CRITICAL TECHNOLOGIES

- **<u>JOINT THEME DISCUSSION, THURSDAY 8:30-10:45 A.M.</u>**
  - DISCUSSION BETWEEN AUDIENCE & ALL THEME ELEMENT SPEAKERS
  - RESOLUTION OF CRITICAL TECHNOLOGIES ACROSS THEME

PRIORITIZATION CRITERIA
(LISTED IN ORDER OF IMPORTANCE)

1. **CRITICAL ENABLING TECHNOLOGIES**
   - TECHNOLOGIES WHICH ARE CRITICAL FOR FUTURE U.S. SPACE MISSIONS
2. **COST REDUCTION TECHNOLOGIES**
   - TECHNOLOGIES WHICH CAN DECREASE COSTS OR COMPLEXITY (e.g., DEVELOPMENT, LIFE-CYCLE, OPERATIONS)
3. **BROAD APPLICATION TECHNOLOGIES**
   - TECHNOLOGIES WHICH CAN IMPROVE OR ENHANCE A VARIETY OF SPACE MISSIONS
4. **REQUIRE IN-SPACE VALIDATION**
   - TECHNOLOGIES WHICH REQUIRE THE SPACE ENVIRONMENT OR MICRO-GRAVITY FOR VALIDATION OR EXPERIMENTATION

APPENDIX

SUMMARY OF
AUTOMATION & ROBOTICS THEME FROM 1985 WILLIAMSBURG, VA, IN-SPACE RT&E WORKSHOP

— QUOTED FROM WORKSHOP EXECUTIVE SUMMARY —

QUOTES FROM 1985 WILLIAMSBURG, VA
RT&E WORKSHOP

AUTOMATION AND ROBOTICS

OBJECTIVES/CAPABILITIES

- o VALIDATE ROBOTIC IN-SPACE OPERATIONS CAPABILITY
  - DOCKING - 1988
  - SATELLITE SERVICING - 1990
  - STRUCTURAL ASSEMBLY - 1992
  - IVA ASSISTANT - 1996
  - EVA ASSISTANT - 2000
- o EVOLVE ROBOTIC IN-SPACE OPERATIONS CAPABILITY
  - TELEPRESENCE - 1990
  - SUPERVISORY CONTROL - 1994
  - AUTONOMOUS OPERATIONS - 1998
- o SYSTEM AUTONOMY CAN BE DEMONSTRATED ON GROUND

QUOTES FROM 1985 WILLIAMSBURG, VA
RT&E WORKSHOP

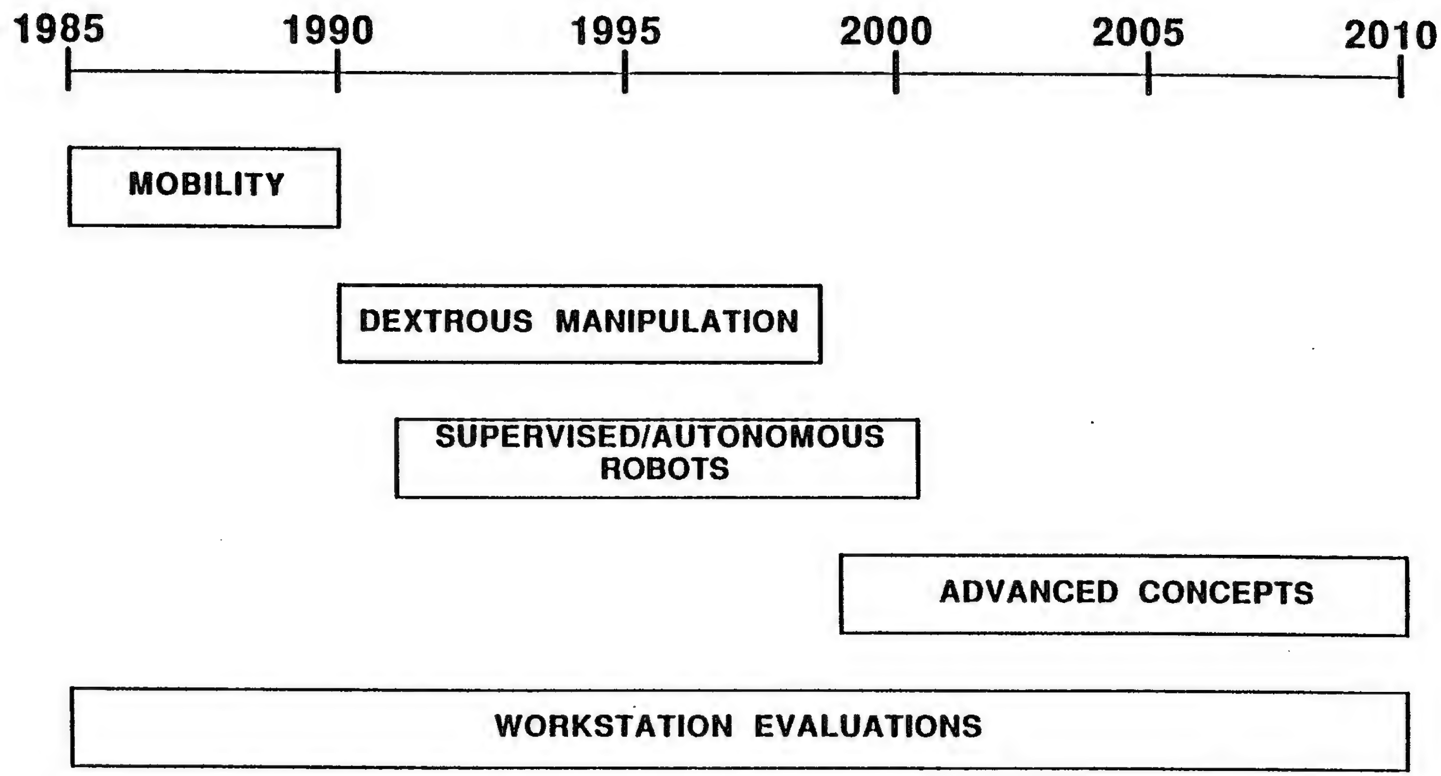
WHY IN-SPACE EXPERIMENTS

- EVALUATE ZERO "G" VS. ONE "G" DYNAMICS FOR:
  - MECHANICAL CONFIGURATIONS
  - PROXIMITY OPERATIONS
  - FLUIDS, SOLIDS, GASES
- DEVELOP DESIGN/OPERATIONAL DATA BASE
- VALIDATE PROTO FLIGHT HARDWARE/SOFTWARE/ PROCESSES
- EVALUATE MAN/MACHINE PERFORMANCE ON-ORBIT
- EVALUATE GROUND MODELS/SIMULATIONS
- EVALUATE LONG TERM SPACE EFFECTS ON SYSTEMS

QUOTES FROM 1985 WILLIAMSBURG, VA
RT&E WORKSHOP

AUTOMATION AND ROBOTICS

EXPERIMENT THRUSTS



QUOTES FROM 1985 WILLIAMSBURG, VA RT&E WORKSHOP

PRE-IOC	IOC (92-97)	FOC (97-BEYOND)
• SINGLE ARM TELEOPERATOR	• DUAL ARM TELEOPERATOR COORDINATION	• MULTI-ARM COORDINATION
• TELEOPERATION FROM EARTH • COMBINED TRANSLATION/ MANIPULATION	• TELEPRESENCE	• AUTONOMOUS ROBOTICS • MULTIPLE ROBOT COORDINATION
• FIXED ON-STATION RMS • DOCKING	• MOBILE ON STATION RMS • TELEOPERATED FREE-FLYING OPERATIONS	• FREE-FLYING AUTONOMOUS PROXIMITY OPERATIONS
	• FREE-FLYER AND DUAL-ARM COLLISION AVOIDANCE	• MULTIPLE ARM COLLISION AVOIDANCE
	• CAD-DRIVEN POSITION REGISTRATION (ON S/S)	
• END-EFFECTOR DEFINITION	• (EVOLVING)	• (EVOLVING)
• MECHANICAL ASSEMBLY PROCESS	• JOINTING	• WELDING
• WORK STATION HW/SW/MM INTERFACES	• (EVOLVING)	• (EVOLVING)
• SENSOR ACCOMMODATIONS	• (EVOLVING)	• (EVOLVING)
• SPACE EFFECTS ON TELEOP. CAPABILITY	• (EVOLVING)	• (EVOLVING)
	• ZERO G MATERIALS HANDLING	• (EVOLVING)

QUOTES FROM 1985 WILLIAMSBURG, VA
RT&E WORKSHOP

PRE-IOC	IOC (92-97)	FOC (97-BEYOND)
• FAILURE DETECTION • FAILURE ISOLATION • FAULT TOLERANCE	• FAULT TOLERANT (EVOLVING) • FAULT REPAIR	• FAULT REPAIR (EVOLVING)
• ADVANCED AUTOMATION SOFTWARE ALGORITHMS	• REAL-TIME PLANNING • INDEPENDENT EXPERT	• INTERACTIVE AI/EXPERT SYSTEMS
• IMPROVED SATELLITE SERVICING TOOLS	• TELEOPERATOR SATELLITE SERVICING	• AUTONOMOUS SATELLITE SERVICING & REPAIR BY ROBOTS
	• ROBOTIC INSPECTION (SENSOR DEPENDENT)	• ROBOTS REPAIR BY ROBOTS
• WORKLOAD POWER CONSUMPTION EXPERIMENTS		
• ROBOTIC VISION AND IMAGERY OPTIMIZATION	• SPACE EFFECTS ON VISION SYSTEMS	
• AUTONOMOUS ORBIT TRANSFER		
• COMPLIANCE TECHNIQUES	• (EVOLVING)	• (EVOLVING)
• MASS MOVEMENTS STUDIES	• MOMENTUM COORDINATION	• (EVOLVING)
• VOICE CONTROL/INTERACTION	• (EVOLVING)	• (EVOLVING)

QUOTES FROM 1985 WILLIAMSBURG, VA
RT&E WORKSHOP

AUTOMATION AND ROBOTICS

EXPERIMENT LIST

1988	PROXIMITY MANEUVERING
1989	TELEOPERATED MANEUVERING (MMU)
1990	SMART FRONT END TECHNOLOGY
1992	SATELLITE SERVICING
1994/6	SUPERVISORY STRUCTURAL ASSEMBLY
1996	IVA ROBOT
2000	AUTONOMOUS SPACE ROBOT
2010	SPACE SPIDER

CONTINUOUS WORKSTATION EVALUATION AND IN-SPACE WORKLOAD MEASUREMENTS

QUOTES FROM 1985 WILLIAMSBURG, VA
RT&E WORKSHOP

AUTOMATION AND ROBOTICS

ACCOMMODATION ISSUES

- "ROBOT FRIENDLY" INTERFACES FOR SERVICING, ASSEMBLY, AND DOCKING
- STANDARD UTILITIES REQUIRED FROM MOBILITY SYSTEMS (RMS, MRMS, OMV, OTV, ETC.)
- SAFETY
- COMPUTING POWER, DATA STORAGE, SYSTEM ARCHITECTURES
- STANDARDS FOR END EFFECTORS, ARMS, HOLDERS, ETC.
- MASS/VOLUME MODEST
- ASTRONAUT TRAINING REQUIRED
- FORMATION FLYING REQUIRED
- EVA NECESSARY IN SOME CASES
- IVA ACTIVITY REQUIRED
- HIGH BANDWIDTH VIDEO/ENCRYPTION COMMUNICATIONS SYSTEM

QUOTES FROM 1985 WILLIAMSBURG, VA
RT&E WORKSHOP

RECOMMENDATIONS

- ACCELERATE EXPERIMENT SCHEDULE - IMPACT SPACE STATION
- ACTIVE FOLLOW-UP TO EMBED TECHNOLOGY ACCOMMODATION ISSUES WITH SPACE STATION
- ESTABLISHMENT OF IN-SPACE TECHNOLOGY ADVOCACY COMMITTEE
- WORK WITH ULTIMATE USER GROUPS
- ENCOURAGE USERS TO COME FORWARD
- EXPLORE CREATIVE WAYS OF COST SHARING
- DEVELOP AND DISSEMINATE SPACE STATION IN-SPACE RESEARCH CAPABILITY
- BROADEN RESEARCH USER LIAISON WITH STATION
- COORDINATE BETWEEN PANELS - DISTRIBUTE TO PARTICIPANTS
- ESTABLISH CONTINUING MAIL LIST AND FOCAL POINTS

5.1 ROBOTIC SYSTEMS

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ROBOTICS

AL MEINTEL
NASA LARC

INTRODUCTION/BACKGROUND

- AUTOMATIC MACHINE
  SPECIAL PURPOSE MECHANISM
- REPROGRAMMABLE MULTIFUNCTIONAL MACHINE
  INDUSTRIAL ROBOT
- ADAPTIVE ROBOT
  SENSOR BASED
- TELEROBOT
  SUPERVISED MACHINE
- INTELLIGENT ROBOT
  GOAL DRIVEN

MISSION APPLICATIONS

- ASSEMBLY
- INSPECTION
- SERVICING
- EXPERIMENTATION
- MANUFACTURING
- REPAIR
- CONSTRUCTION
- EXPLORATION

TECHNOLOGY NEEDS

- MECHANISMS
- SENSORS
- CONTROL
- PLANNING
- FAULT TOLERANCE
- SYSTEMS ARCHITECTURE

IN-SPACE EXPERIMENTATION NEEDS/VOIDS

- MECHANISMS
  - REDUNDANT MANIPULATORS WITH LOW WEIGHT & POWER
  - POSITIVE RETENTION OF END EFFECTORS/TOOLS
  - MOBILITY
- SENSORS
  - END POINT DETERMINATION
  - COLLISION DETECTION
  - DATA CORRELATION
- CONTROLS
  - FLEXIBILITY
  - DISTURBANCE COMPENSATION
  - DYNAMIC INTERACTION
- OPERATOR INTERFACE
  - DYNAMIC SIMULATION
  - MONITORING
  - INTERACTIVE REPLANNING

SUMMARY/RECOMMENDATIONS

- O IN-SPACE EXPERIMENTS
  - FLEXIBILITY
  - DYNAMIC INTERACTIONS
  - FLIGHT QUALIFIED HARDWARE
    - MECHANISMS
    - SENSORS
    - COMPUTERS
  - SYSTEM VALIDATION
- O STANDARDIZATION
- O EFFICIENT ROBOTIC PROGRAMMING
- O FAULT TOLERANCE/REDUNDANCY
- O TELEROBOTICS

ROBOTICS

T.M. Depkovich
J.R. Spofford

MARTIN MARIETTA
SPACE SYSTEMS CO.

INTRODUCTION/BACKGROUND

- R&D ACTIVITIES HAVE DEVELOPED AN ARRAY OF TECHNIQUES FOR ROBOTIC SYSTEM CONTROL
- MATURE AND NEAR-MATURE AREAS INCLUDE:
  - POSITION CONTROL
  - COMPLIANT CONTROL
  - COORDINATED DUAL ARM CONTROL
- FEASIBILITY DEMONSTRATIONS HAVE INCREASED CONFIDENCE IN TECHNOLOGY
- MISSION APPLICATION ASSESSMENT SUFFERS FROM "CHICKEN AND EGG" SYNDROME
  - MISSIONS UNWILLING TO COMMIT WITHOUT FIRM DEFINITION OF ROBOTIC CAPABILITY
  - ROBOTIC CAPABILITY ONLY GENERALLY DEFINED BECAUSE OF LACK OF MISSION SUPPORT
  - EXAMPLE: "DESIGN FOR SERVICING"
- BROAD RANGE OF POTENTIAL APPLICATIONS
  - EVA: CONSTRUCTION, INSPECTION, REFURBISHMENT, REPAIR, CONTINGENCY
  - IVA: HOUSEKEEPING, EXPERIMENTS

TECHNOLOGY NEEDS

- DEMONSTRATIONS PERFORMED OVER THE PAST SEVERAL YEARS HAVE SHOWN FEASIBILITY OF ALL MAJOR TECHNOLOGY ELEMENTS NECESSARY FOR ROBOTIC SERVICING PROGRAM
- MAJOR SHORTFALL AT THIS TIME IS A LACK OF CONSENSUS ON MEANS OF SPECIFYING MANIPULATOR SYSTEM PERFORMANCE REQUIREMENTS AND VALIDATING SYSTEM PERFORMANCE
- VIRTUALLY ALL CURRENT SPECIFICATIONS ARE STATIC; TO BE MEANINGFUL AND USEFUL, DYNAMIC SPECIFICATIONS ARE ALSO REQUIRED
- SOLUTION IS ACHIEVED THROUGH THE UNDERSTANDING OF RELATIONSHIP BETWEEN TASK FUNCTIONAL DESCRIPTION AND MANIPULATOR CLOSED-LOOP DYNAMIC IMPEDANCE
- EQUIVALENT TO ASSIGNING UNITS ON DEXTERITY
- THREE POTENTIAL APPROACHES TO ESTABLISHING THESE RELATIONSHIPS
  - ANALYTICAL (NOT LIKELY)
  - SIMULATION (LIKELY WITH ADVANCED CAD/CAE)
  - EMPIRICAL (BEST NEAR-TERM SOLUTION)

IN-SPACE EXPERIMENTATION NEEDS/VOIDS

- MAJORITY OF SPACE ISSUES CAN BE ANSWERED THROUGH GROUND BASED TESTING AND EXPERIMENTATION
- SPACE BASED EXPERIMENTS SHOULD BE VIEWED AS FINAL LINK IN CHAIN OF VALIDATION STUDIES NECESSARY PRIOR TO HANDOVER TO OPERATIONAL COMMUNITY
- DEDICATED EXPERIMENTAL TESTBED AVAILABLE TO RESEARCH COMMUNITY FOR GENERAL INVESTIGATIONS
  - MECHANISMS
  - SENSORS
  - CONTROL
  - PROCESSING
  - MMI
- KEY INITIAL EXPERIMENTS
  - CONTROL LAW VALIDATION
    - COMPLIANT CONTROL
    - CONTROL WITH LARGE PAYLOADS
    - COORDINATION
    - SUPERVISORY CONTROL
  - PERFORMANCE DATABASE FOR OPERATIONS ASSESSMENT

SUMMARY/RECOMMENDATIONS

- ROBOTIC TECHNOLOGY NOW READY TO ADVANCE TO MATURE TECHNOLOGY STATUS
- THIS REQUIRES THE ABILITY TO UNAMBIGUOUSLY SPECIFY PERFORMANCE REQUIREMENTS; BOTH STATIC AND DYNAMIC
- THIS ABILITY ESSENTIAL TO DESIGN AND VALIDATION PROCESS; AN IMPORTANT FACTOR IN ACHIEVING COST EFFICIENCY
- CAPABILITY NOW EXISTS FOR EMPIRICAL DETERMINATION OF DYNAMIC REQUIREMENTS
- EXPERIMENTAL TESTBED REQUIRED TO SUPPORT ADVANCED RESEARCH
- KEY TO TESTBED SUCCESS IS FLEXIBILITY IN ACCEPTING NEW TECHNOLOGY
  - MECHANISMS
  - SENSORS
  - PROCESSING
  - ALGORITHMS
  - MMI
- LAST STEP IS FINAL VALIDATION OF TECHNOLOGY

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ROBOTS IN SPACE

PROFESSOR DELBERT TESAR

Carol Cockrell Curran Chair in Engineering

THE UNIVERSITY OF TEXAS AT AUSTIN

INTRODUCTION / BACKGROUND

TECH BASE ISSUES FOR ROBOTICS

I. LIGHTWEIGHT
   1. ROBOTS ARE LIMBER
   2. MUST BE MADE ELECTRONICALLY RIGID
   3. REQUIRES COMPLETE PARAMETRIC MODEL
   4. LEVEL OF CONTROL FAR BEYOND PRESENT CAPABILITY

II. PRECISION UNDER DISTURBANCE
   1. PRECISION LIGHT MACHINING
   2. REAL TIME DYNAMIC MODEL
   3. ADAPTIVE CONTROL
   4. FEEDFORWARD COMPENSATION

III. MAN-MACHINE INTERFACE
   1. NEED INCREASES WITH BETTER TECHNOLOGY
   2. SHOULD BE KINESTHETIC (ANALOG)
   3. FORCE FEEDBACK ESSENTIAL
   4. GENERIC UNIVERSAL MANUAL CONTROLLER

IV. DYNAMICS OF DOCKING
   1. SHOCK TO STATION UNDESIRABLE
   2. SATELLITE SPIN AND WOBBLE IS COMPLEX
   3. PRESENTLY REQUIRES 8 TO 10 hours
   4. SOPHISTICATED MANIPULATOR DYNAMICS REQUIRED

V. LEVEL OF TECHNOLOGY REQUIRED
   1. FAR BEYOND TODAY'S INDUSTRIAL ROBOT
   2. GEOMETRY MUST BE MORE GENERIC (PARALLEL)
   3. DYNAMIC CONTROL TECHNOLOGY GROSSLY INADEQUATE
   4. BALANCE OF ELECTRICAL AND MECHANICAL ESSENTIAL

AUTOMATION & ROBOTICS	IN-SPACE TECHNOLOGY EXPERIMENS WORKSHOP DECEMBER 6-9, 1988	ROBOTIC SYSTEMS

GENERIC TECHNOLOGY NEEDS / VOIDS

NEEDS	REMARKS
1. MULTI-TASK CAPABILITY	NUMBER OF DIFFERENT PHYSICAL TASKS FEASIBLE
2. LEVEL OF MACHINE INTELLIGENCE	LEVEL OF INTEGRATION OF COMPUTER HARDWARE, SOFTWARE, ARTIFICIAL INTELLIGENCE, ETC.
3. TIME EFFICIENT OPERATION	SPEED OF PERFORMANCE RELATIVE TO HUMAN ACTING ALONE
4. UNSTRUCTURED TASK LEVEL	LEVEL OF NUMERICAL UNCERTAINTY IN TASK SPECIFICATION
5. GEOMETRICAL DEXTERITY	EFFECTIVE MOTION RANGE (LINEAR AND ANGULAR) OF THE END-EFFECTOR
6. PORTABILITY AND MOBILITY	ABSOLUTE MOVEMENT OF SHOULDER BASE WITH WITH OR WITHOUT HUMAN ASSISTANCE
7. PRECISION	ABSOLUTE PRECISION OF POSITIONING OF END-EFFECTOR IN WORLD COORDINATES

SPECIFIC TECHNOLOGY NEEDS / VOIDS

REAL-TIME SYSTEM MODELING FOR MODEL REFERENCE ADAPTIVE CONTROL

NEEDED DEVELOPMENT

- DEMONSTRATE MODEL REFERENCE CONTROL
  - RIGID LINK MODEL
  - COMPENSATE FOR APPLIED LOADS
  - COMPENSATE FOR INERTIA LOADS
- EXPAND TO INCLUDE DEFLECTIONS
  - LINK FLEXIBILITY
  - ACTUATOR FLEXIBILITY
- ESTABLISH OPERATIONAL SOFTWARE
- DEMONSTRATE IN ACTUAL MACHINING OPERATIONS

TASK DESCRIPTION

- EXPAND RANGE OF APPLICATIONS
  - FOR GENERIC MANUFACTURING SYSTEMS
  - USE FEED FORWARD COMPENSATION
- ON LINE COMPUTATION
  - FULL MODELING MATRICES
  - REAL TIME ($<$ 30 msec.)
- ARRAY PROCESSOR IMPLEMENTATION
  - PIPELINED COMPUTATION
  - RECURSION IN ALGORITHM

ROBOT TECHNOLOGY NEEDS FOR SPACE

I. ASSEMBLY OF SPACE STRUCTURES
   1. HANDLING OF LARGE MODULES
   2. PRECISE SUB-ASSEMBLY TASKS
   3. PRECISION WELDING AND FORMING
   4. PRECISION LIGHT MACHINING

II. SPACE STATION MAINTENANCE AND REPAIR
   1. CONTINUOUS INSPECTION REQUIRED
   2. 40% OF REPAIRS TO BE UNPLANNED
   3. UNSTRUCTURED TASK ENVIRONMENT
   4. PRECISION UNDER DISTURBANCE

III. SATELLITE SERVICING AND REPAIR
   1. 75 MISSIONS/YEAR
   2. UNSTRUCTURED TASKS
   3. SOME PRECISION WORK UNDER DISTURBANCE
   4. DOCKING DYNAMICS CRITICAL

IV. HAZARDOUS MANUFACTURING AND LABORATORY EXPERIMENTS
   1. CLUTTERED ENVIRONMENT IN MODULE
   2. CLEAN ROOM ATMOSPHERE
   3. ABSOLUTE STABILITY DESIRED
   4. FURNACE RENOVATION CRITICAL

V. MAINTENANCE OF ROBOTS
   1. SOFTWARE ADAPTABILITY TO CHANGE IN PARAMETERS
   2. MODULARITY FOR MAINTAINABILITY
   3. MODULE REPLACEMENT FOR TECHNOLOGY UP-DATE
   4. DUALITY IN CRITICAL MAINTENANCE OPERATIONS

IMMEDIATE RESEARCH NEEDS FOR SPACE STATION ROBOTICS

- ARCHITECTURE OF ROBOTICS SYSTEMS
- UNIVERSAL MAN-MACHINE INTERFACE FOR ROBOTIC MANIPULATOR SYSTEMS
- CONTROL OF MULTIPLE ARM ROBOTIC SYSTEMS
- ROBUST CONTROL OF FLEXIBLE "CHERRY PICKER" ROBOTIC MANIPULATOR
- REALTIME SYSTEM MODELING FOR MODEL REFERENCE ADAPTIVE CONTROL
- METROLOGY FOR ROBOTIC SYSTEMS

5.2 TELEOPERATIONS

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SPACE TELEOPERATIONS, NOW AND FUTURE

Charles R. Price
TELEOPERATOR SYSTEMS BRANCH
JOHNSON SPACE CENTER

INTRODUCTION/BACKGROUND

- THE SPACE SHUTTLE DEPLOYMENT AND RETRIEVAL SYSTEM IS THE STATE OF THE ART FOR IN-SPACE TELEOPERATIONS

- THE PDRS CONSISTS OF THE REMOTE MANIPULATOR SYSTEM AND ITS ANCILLARY EQUIPMENT MOUNTED ON THE SPACE SHUTTLE ORBITER

- THE PDRS FUNCTIONALITIES ARE:
  - GRAPPLE, TRANSPORT, ORIENTATION, AND RELEASE OF A PAYLOAD
  - TRACK, CAPTURE, GRAPPLE, TRANSPORT, ORIENTATION, AND BERTHING OF A SATELLITE
  - EVA CREW TRANSPORT, POSITIONING, ORIENTATION VIA GRAPPLED MOBILE FOOT RESTRAINT
  - LOCAL ILLUMINATION VIA RMS-MOUNTED LIGHTS
  - DIRECTIONAL, AUGMENTED VIEWING VIA RMS-MOUNTED CCTV
  - FREESTREAM EXPERIMENT SENSOR POSITIONING
  - POWER AND DATA INTERFACE SERVICES FOR PAYLOADS
  - RESOURCE FOR CREATIVE SOLUTIONS TO UNPLANNED PROBLEMS

NEAR TERM FUTURE TELEOPERATOR APPLICATIONS

- ON-ORBIT:
  - ORBITER-BASED SPACE STATION ASSEMBLY
  - SPACE STATION-BASED SPACE STATION ASSEMBLY
  - SATELLITE SERVICING
- TERRESTRIAL SPACE APPLICATIONS:
  - KSC TURN-AROUND OPERATIONAL COST REDUCTION APPLICATION, e.g.:
    - TILE INSPECTION
    - PAYLOAD BAY INSPECTION
  - NSTS TURNAROUND COSTS ARE $250 MILLION/FLIGHT
  - SUCCESSFUL GROUND APPLICATIONS ENHANCE ON-ORBIT APPLICATIONS

LONGER TERM TELEOPERATOR APPLICATIONS (WITH TRENDS TOWARDS TELEROBOTICS)

- EXPANDED ON-ORBIT SERVICING OF SATELLITES
- EXPANDED SHUTTLE TURNAROUND OPERATIONAL SUPPORT
- ON-ORBIT MAINTENANCE OF SPACE STATION
- ON-ORBIT SERVICING OF PLATFORMS, INCLUDING HARVESTING OF PRODUCTS
- ON-ORBIT ASSEMBLY OF LUNAR AND DEEP SPACE EXPLORATORY VEHICLES
- REMOTE LUNAR MINING OPERATIONS

TECHNOLOGY NEEDS FOR SPACE SHUTTLE PAYLOAD DEPLOYMENT AND RETRIEVAL SYSTEM SUPPORT TO SPACE STATION ASSEMBLY

- FORCE/TORQUE FEEDBACK
- CONSTRAINED MOTION CONTROL FUNCTIONALITY
  - RATE COMMAND TO CONTACT TRANSITION
  - RATE COMMAND WITH VARIABLE RESISTANCE LOADING
  - SPLIT AXIS MIXED MODES
- LOW SCAR GRAPPLE FIXTURE
- DISPLAY OF COMPLEX ASSEMBLY WORKSPACES TO CREW
- PRACTICAL COLLISION AVOIDANCE (INFERS LIMITED MACHINE VISION)
- SINGLE WORKSTATION CONTROL OF MULTIPLE, HIERARCHIAL (AND SOME PARALLEL) MANIPULATORS
- FAULT TOLERANCE BY DESIGN TO IMPROVE MISSION SUCCESS PROBABILITIES

PERCEIVED VOIDS IN THE IN-SPACE EXPERIMENTS REGARDING TELEOPERATORS

- ON-ORBIT:
  - DISPLAY OF COMPLEX (ASSEMBLY) WORKSPACE UNDER ORBITAL LIGHTING CONDITIONS TO CREW
  - COLLISION AVOIDANCE SENSING, CALCULATION, AND DISPLAY TO CREW
  - SINGLE WORKSTATION CONTROL OF
    - HIERARCHIAL SETS OF MANIPULATORS
    - PARALLEL SETS OF MANIPULATORS
    - TOTAL DEGREES OF FREEDOM EXCEEDING FIFTY OR MORE
  - DEMONSTRATION/VERIFICATION OF MATH MODELED CONSTRAINED MOTION AND CONTACT DYNAMICS
  - FAILURE DETECTION, ISOLATION, AND AUTOMATIC RECONFIGURATION OF A TELEOPERATOR SYSTEM
  - DISTRIBUTED, JOINT-LEVEL REPROGRAMMABLE MICROPROCESSING FOR AN OPERATIONALLY ADAPTIVE TELEOPERATOR

- TERRESTRIAL RELATED:
  - FEEDFORWARD CONTROL FOR GROUND COMMAND OF ON-ORBIT TELEOPERATOR
  - SHUTTLE TURNAROUND COST SAVINGS APPLICATIONS

SUMMARY/RECOMMENDATIONS

- ASSEMBLY OF COMPLEX WORKPIECES IS THE MAJOR NEAR TERM TECHNOLOGY DRIVER FOR IN-SPACE TELEOPERATORS
- IN-FLIGHT EXPERIMENTS SUPPORTING ASSEMBLY WILL ALSO APPLY TO SATELLITE SERVICING TELEOPERATION
- RECOMMEND MORE EMPHASIS BE PLACED ON PRACTICAL COLLISION AVOIDANCE AND DISPLAY OF COMPLEX WORKSPACE TO CREW

TELEOPERATION

Paul B. Pierson
GE AEROSPACE

INTRODUCTION/BACKGROUND

- SPACE TELEOPERATION
  - CANDIDATE MISSIONS DEFINED
  - COST EFFECTIVENESS UNDER REVIEW
  - TELEOPERATION IS POTENTIALLY A VIABLE OPTION
- TECHNOLOGY BASE
  - INDUSTRIAL ROBOTICS
  - UNDERSEA, NUCLEAR POWER PLANT TELEOPERATIONS
- SPACE TELEOPERATION/SUPERVISORY CONTROL
  - COMBINATION OF ROBOTICS AND TELEOPERATIONS
  - COMPLEX OPERATOR INTERFACE
  - HIERARCHICAL CONTROL/INFORMATION ARCHITECTURE
  - COMMUNICATION TIME DELAYS
  - MUST PERFORM PLANNED/UNPLANNED TASKS
  - SPACE CONDITIONS

CAPABILITIES REQUIRED FOR MISSION APPLICATION TASKS

- CAMERA/INSTRUMENT POSITIONING FOR INSPECTION
- HEAVY/LIGHT OBJECT MANIPULATION AND POSITIONING
- MANIPULATION IN FREE-SPACE AND WITH CONTACT CONSTRAINED MOTIONS
- APPLICATION OF FORCE

MISSION APPLICATIONS

- INSPECTION (ROUTINE OR DIAGNOSTIC)
- ORU/PAYLOAD EXCHANGE (PAYLOAD UPGRADE, EXPERIMENT REPLACEMENT)
- REFURBISHMENT/REPLENISHMENT OF EXPENDABLES (FUELS, CRYOGENS)
- ASSEMBLY OF LARGE SPACE STRUCTURES, COMPONENTS
  - SPACE STATION TRUSSES AND UTILITY TRAYS
  - LARGE ANTENNAS, NUCLEAR POWERED PLATFORMS
- COMPONENT REPLACEMENT
  - CONTAIMINATED OR WORN PARTS
- INSTRUMENT ADJUSTMENT, CALIBRATION
  - SPACE TELESCOPE, EARTH OBSERVATION SYSTEM
- REPAIR/CONTINGENCY OPERATIONS (SOLAR MAX)
- TELESCIENCE
- MANUFACTURING

MISSION PLATFORMS

- SPACE STATION
  - MASSIVE PLATFORM BASE
  - EVA BACKUP: CONTINGENCY EVENTS, SERVICE THE SERVICER
- UNMANNED PLATFORM (e.g., POLAR, GEO)
  - LOW MASS PLATFORM: CONTROL DYNAMICS ISSUES, INTERACTION WITH OTHER FLEXIBLE STRUCTURES
  - LONG PERIODS OF INACTIVITY
  - NO EVA BACKUP

OPERATOR INTERFACE TECHNOLOGY NEEDS

- INTELLIGENT DISPLAYS
  - EYES/HANDS BUSY OPERATION
  - MUST (ONLY) PROVIDE CRITICAL INFORMATION
- VISUAL PERCEPTION SYSTEMS
  - POSITION
  - FORCE
- HAND CONTROLLERS
  - POSITION/RATE CONTROL
  - FORCE REFLECTION OPTION
- SPEECH RECOGNITION/SYNTHESIS
  - STRESS
  - ENVIRONMENT

CONTROL SYSTEM TECHNOLOGY NEEDS

- STABILITY GIVEN WIDE RANGE OF MANIPULATION SPEEDS, OBJECT MASSES
- CONTROL PARAMETERS VARY WITH TASK/ENVIRONMENT
  - GAIN VALUES FOR POSITION/RATE CONTROL
  - PID GAINS FOR CLOSED LOOP FORCE CONTROL
  - FORCE LIMITS
- COMMUNICATION TIME DELAYS
  - WITHIN ON-BOARD CONTROL ARCHITECTURE
  - ROUND TRIP TO REMOTE OPERATOR
  - IMPACTS SPEED OF MANIPULATION, FORCE CONTROL SENSITIVITY, VIABILITY
- SIMULATION
  - GROUND HARDWARE LIMITED BY 1-G
  - SYSTEM NON-LINEARITIES DIFFICULT TO MODEL
  - VALIDITY OF EMPIRICALLY DERIVED PARAMETERS

TECHNOLOGY NEEDED IN HIERARCHICAL CONTROL/INFORMATION ARCHITECTURES

- MERGE MANUAL/PROGRAMMED TASKS
  - TASK SCRIPT AUTHORING TOOLS
- ENABLE GROWTH TOWARD INCREASING AUTONOMY
  - PLANNING/REPLANNING GIVEN INTERVENING HUMAN ACTIONS
- IMPLEMENTATION IN FLIGHT QUALIFIED PROCESSORS
  - CONSTRAINTS IMPOSED BY PLATFORM DATA COMMUNICATIONS
- SUPERVISORY COMMAND LANGUAGE

PROBLEMS ASSOCIATED WITH HUMAN CONTROL OF SPACE MANIPULATORS

- LIMITED WORKSPACE VIEWS
  - CAMERA POSITIONS FOR OBJECT GRASPING, HIDDEN SURFACES
  - NEED STEREO OR MULTIPLE VIEWS FOR UNSTRUCTURED TASKS
- HUMAN INTERACTION WITH PLATFORM CONTROL DYNAMICS DURING TELEOPERATION
- AVOIDANCE OF MANIPULATOR SINGULARITIES
  - DURING MANUAL CONTROL
  - STARTING PROGRAMMED TRAJECTORIES AFTER MANUAL POSITIONING
- COLLISION AVOIDANCE
  - ROBOT VERSUS WORKSPACE
  - CARRIED OBJECT VERSUS WORKSPACE
- REHEARSAL
  - GROUND AND IN-FLIGHT
  - CONTROL DYNAMICS
  - MANIPULATOR STIFFNESS, STRENGTH
  - TIME BETWEEN REHEARSAL AND ACTION
- MANY CONTROL PARAMETERS NEED TO BE SET WHEN UNPLANNED TASKS ARE TO BE PERFORMED

IN-SPACE EXPERIMENTATION NEEDS/VOIDS, MAN-MACHINE INTERFACE

- TELEOPERATION WITH OPERATOR IN MICROGRAVITY
  - FORCES EXPERIENCED WITH HAND CONTROLLERS
  - IMPACT ON VOICE ACOUSTICS FOR SPEECH RECOGNITION
- TELEOPERATION WITH OPERATOR ON GROUND
  - LIMITED COMMUNICATION BANDWIDTHS
  - TIME DELAYS
- CAMERA SYSTEM CONTROL/ADEQUACY
  - SELECTION, POSITIONING, POINTING, ZOOM, FOCUS, IRIS
  - LIGHTING GIVEN DYNAMIC SOLAR ILLUMINATION CONDITIONS
  - COMMUNICATION BANDWIDTH
- MANUAL SELECTION OF CONTROL PARAMETERS FOR UNPLANNED TASKS
- DYNAMIC INTERACTION BETWEEN PLATFORM, TELEROBOT/OBJECT, OPERATOR
- ACCURACY, STABILITY OF LIGHT MANIPULATOR
  - GIVEN WIDE RANGE OF OBJECT MASSES
- ACCURACY OF COMPUTER SIMULATION DYNAMIC MODEL
- VALIDITY/ACCURACY OF CONTROL PARAMETERS
  - DERIVED/DEMONSTRATED ON GROUND SIMULATION
  - HOW TO TEST PRIOR TO EXECUTING SINGULAR EVENT

multimode operator interfaces
intelligent displays
hierarchical control
communication time delay
visual perception systems

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BACKGROUND

* Solid man-in-space successes in Mercury, Gemini, Apollo. Solid automation demonstrations in deep space, shuttle RMS. Some questions about need for man-in-space in the future, possibilities for remote control.

* Forty years of teleoperator experiments and operations. in nuclear plants, undersea, construction, and space.

* Steadily evolving capability of teleoperation and telerobotics. (Reality has lagged public and in some cases R&D rhetoric, but nevertheless is overtaking NASA's actual preparedness.)

* NASA tradition of attention to empirical human factors, but spotty development of human factors discipline outside.

* Fallacious tendency of Congress and US public to see human participation in space and automation/robotics as mutually exclusive. (They should be seen as symbiotic.)

* Legitimate conservatism re human life, resultant demand for reliable non-expendable hardware have inhibited progress where hardware could be expendable without endangering life.

* Growing competition from Europe and Japan in space technology.

* Current interest in commercial space vehicles.

TECHNOLOGY NEEDS IN TELEOPERATION AND TELEROBOTICS

- Flexible, human friendly supervisory command languages which mix analogic and symbolic elements, and enhance computer understanding.
- means to control redundant degree-of-freedom kinematics (arms of ≥ 7 DOF, arms plus vehicles plus hands).
- Operator adjustable impedance between master and arm, slave and task.
- Video aids to enhance depth: stereo and other.
- Predictor instruments and other means to accommodate time delay in both video and force, and predict contact.
- Manipulator arms which are lighter, stiffer (adjustable), and of higher bandwidth and control precision.
- Smart end effectors having more dexterity (more degrees of freedom).
- Higher resolution and more robust touch and proximity sensors.
- Touch display to hands, eyes, ears or other parts of body.

TECHNOLOGY NEEDS IN TELEROBOT DESIGN, MISSION PLANNING AND MONITORING

* Theory of telepresence, what it is and what it contributes.
* Theory and experimental measures of manual dexterity.
* Techniques for control of unpredictable dynamics.
* Computer understanding of operator queries and stated intentions (for expert systems and telerobot control aids).
* Real time simulation and associated graphics for on-line multiobjective control decisions and planning.
* Computer-based aids for telerobot failure detection, diagnosis and recovery.
* Theory of allocating, trading and sharing of telerobot control functions between human and computer.
* Techniques for simulating large-scale space teleoperation / telerobotics operations on the ground.

PROPOSED EXPERIMENTS IN SPACE

* Demonstrations of teleoperator (direct) and telerobot (supervisory) control in dynamic tasks, e.g., throwing and catching objects, rendezvousing with tumbling satellite and inspecting or inserting/removing module.
  * with and without force feedback.
  * with 6 and redundant degrees-of-freedom.
    * one arm-hand
    * two arm-hands
    * vehicle plus arm-hand simulataneously.
  * controlled from the ground.
  * using touch when vision is obscured.
* Demonstration of predictor instruments to accommodate time-delayed video and force feedback.
* Demonstrations of telepresence.
* Demonstrations of telescience by scientists on ground.
* Demonstration of failure recovery drills by various human and machine combinations.

5.3 ARTIFICIAL INTELLIGENCE

IN-SPACE EXPERIMENTS IN ARTIFICIAL INTELLIGENCE

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BRANCH CHIEF, RIA
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Nancy Sliwa
RIA, NASA AMES RESEARCH CENTER
ATB, NASA LANGLEY RESEARCH CENTER

INTRODUCTION/BACKGROUND

- NASA R&D PROGRAMS
  - SYSTEMS AUTONOMY TECHNOLOGY PROGRAM (CSTI)
  - SPACE STATION FREEDOM ADVANCED TECHNOLOGY PROGRAM
  - PATHFINDER
- CURRENT CAPABILITIES:
  - INCO EXPERT SYSTEM IN MISSION CONTROL
    *HST SCHEDULER IN END-TO-END TESTING, SHARP, AUTOCLASS
- ARTIFICIAL INTELLIGENCE (AI) ELEMENTS
  - REASONING UNDER UNCERTAINTY
  - LEARNING
  - CAUSAL MODELLING
  - KNOWLEDGE ACQUISITION
  - ADVANCED PLANNING METHODS
  - COOPERATING KNOWLEDGE BASE SYSTEMS
  - VALIDATION TECHNOLOGIES
- DIFFERENCES BETWEEN GROUND- VS. SPACE-BASE AI SYSTEMS
  - AVAILABILITY OF SUFFICIENT PROCESSING POWER AND MEMORY
  - REALTIME CONSTRAINTS
  - RELIABILITY CONSTRAINTS
  - ENVIRONMENTAL UNCERTAINTY
  - PERCEIVED VS. REAL RISK

TECHNOLOGY NEEDS

- BUILDING AND USING VERY LARGE KNOWLEDGE BASES
  - AUTOMATIC KNOWLEDGE ACQUISITION
  - EFFECTIVE KNOWLEDGE COMBINATION FROM MANY SOURCES
  - REPRESENTATION AND OPERATIONALIZATION OF MASSIVE AMOUNTS OF KNOWLEDGE
- COLLABORATION
  - DISTRIBUTED PROBLEM SOLVING
  - MULTIPLE AGENTS
  - GRACEFUL INTERACTION WITH HUMANS
- CAUSAL REASONING
- UNCERTAINTY MANAGEMENT
  - REASONING ABOUT UNCERTAINTY
  - REACTIVE REPLANNING TO COPE WITH UNCERTAINTY
- VALIDATION AND VERIFICATION OF INTELLIGENT SYSTEMS

TECHNOLOGY NEEDS

- PLANNING/SCHEDULING IN REAL, COMPLEX SITUATIONS
- DESIGN
  - STATIC GROUND-BASED DESIGN
  - DYNAMIC FLIGHT-BASED REDESIGN
- MACHINE LEARNING
  - DISCOVERY
  - IMPROVEMENT OF PERFORMANCE WITH EXPERIENCE
  - ACQUIRING EXPERTISE
- SPACEBORNE SYMBOLIC PROCESSORS

IN-SPACE EXPERIMENTATION NEEDS/VOIDS

- FLIGHT TEST NEEDED FOR INTEGRATED HARDWARE/SOFTWARE SYSTEMS, e.g., PROCESSOR LIMITATIONS, ROBOTICS SYSTEMS
- IN GENERAL, AI SOFTWARE SHOULD BE TREATED LIKE ANY OTHER COMPUTER CODE – GROUND SIMULATION SHOULD BE SUFFICIENT FOR VALIDATION. BUT VALIDATION AND VERIFICATION OF AI SOFTWARE IS STILL A RESEARCH ISSUE
  - NEW TECHNIQUES MAY REQUIRE FLIGHT EXPERIMENTATION
  - PERCEIVED RISK MAY ADVISE FLIGHT EXPERIMENTATION

SUMMARY

- AI TECHNOLOGY WILL BE CRITICAL TO FUTURE SPACE MISSIONS FOR BOTH GROUND AND FLIGHT USE
- INTEGRATED HARDWARE/SOFTWARE FLIGHT TESTS WILL BE NECESSARY
- IN GENERAL, GROUND-BASED VALIDATION IS SUFFICIENT FOR SOFTWARE
- SOME FLIGHT VALIDATION MAY BE NECESSARY TO ESTABLISH A "TRACK RECORD" FOR AI SOFTWARE

ARTIFICIAL INTELLIGENCE: AN INDUSTRY VIEW

PRESENTED BY:

David A. Rosenberg,
ISX CORPORATION

INTRODUCTION/BACKGROUND

- AI SPACE APPLICATIONS WILL CLEARLY BE HYBRIDS, INVOLVING CONVENTIONAL AND AI-BASED COMPONENTS TO SOLVE PROBLEMS THAT NEITHER COULD COPE WITH ALONE
- THESE PRODUCTS ARE GENERALLY KNOWN AS INTELLIGENT SYSTEMS. HERE, INTELLIGENCE IMPLIES THE USE OF EXPLICIT KNOWLEDGE (OFTEN META-KNOWLEDGE)
- INTELLIGENT AUTONOMOUS SYSTEMS UTILIZE EXPLICIT KNOWLEDGE OF A TARGET SYSTEM AND OF DESIRED GOALS TO EVALUATE OR CONTROL THE TARGET, WITH VARYING DEGREES OF AUTONOMY
- INTELLIGENT DECISION SUPPORT SYSTEMS EXPLOIT USER KNOWLEDGE, PLUS DOMAIN SPECIFIC KNOWLEDGE TO BETTER AID THE DECISION MAKER

MISSION APPLICATIONS

- SHUTTLE. WHILE NOT "DESIGNED IN" INTELLIGENT SYSTEMS COULD PLAY AN IMPORTANT ROLE
- ADAPTIVE PLANNING TECHNIQUES COULD ASSIST CREW MEMBERS IN PERFORMING NUMEROUS ACTIVITIES, SUCH AS CONDUCTING EXPERIMENTS, OR PERFORMING PAYLOAD CHECKOUT
- GREATER AUTONOMY COULD BE GIVEN TO EXPERIMENTS. KNOWLEDGE GAINED FROM THE EXPERIMENT DESIGNERS COULD REDUCE CREW MONITORING AND PROVIDE BETTER, MORE EFFICIENT CREW INTERFACE WHEN INTERVENTION IS REQUIRED
- SPACE STATION. THE SAME TECHNIQUES DESCRIBED ABOVE COULD PROVIDE EVEN MORE LEVERAGE IF WELL INTEGRATED. SIGNIFICANT IMPROVEMENTS IN OPERATIONS PLANNING, RESOURCE ALLOCATION, AND FAULT DETECTION/CORRECTION COULD BE ACHIEVED. APPLICATION TO THE UNDERLYING DISTRIBUTED COMPUTATION ENVIRONMENT IS ESPECIALLY ATTRACTIVE
- TELEROBOTICS. AUGMENTATION TO THE HUMAN INTERFACE IS ESPECIALLY ATTRACTIVE
  - ADAPTIVE PLANNING COULD BE USED TO PROVIDE HIGH LEVEL TASK PLANNING AND REPLANNING IN CONCERT WITH ACTUAL PROGRESS. THE SELECTION OF VERY LOW LEVEL FEATURES SUCH AS GRIPPING FORCE, FORCE REFLECTION RATIOS, LIGHTING CONTROL, ETC., COULD BE AUTOMATICALLY SELECTED

MISSION APPLICATIONS

- AUTONOMOUS ROBOTICS. HERE, INTELLIGENT AUTONOMOUS SYSTEMS ARE AN ENABLING TECHNOLOGY
  - FOR FULLY AUTONOMOUS OPERATION, GOAL-DIRECTED, HIGH LEVEL PLANNING IS EVEN MORE IMPORTANT
  - KNOWLEDGE OF THE SYSTEM BEING SERVICED, THE SERVER ITSELF, AND OF OVERALL GOALS WILL BE REQUIRED TO PROVIDE THE HUMAN SUPPLIED FEATURES DESCRIBED ABOVE: SITUATION ASSESSMENT, MACHINE VISION, TESTING, ETC. THIS COULD BE A VERY HARD PROBLEM
  - USER DIRECTED SPECIALIZATION OF SKELETAL PLANS COULD ALSO PROVIDE A POWERFUL MECHANISM FOR DEVELOPING NEW PLANS FOR BOTH INTELLIGENT AND DUMB AUTONOMOUS ROBOTS

- PLANETARY MISSIONS. HERE, THE MUCH GREATER NEED FOR AUTONOMY MAKES AI AN ''ENABLING'' TECHNOLOGY. ON UNMANNED MISSIONS, KNOWLEDGE OF MISSION OBJECTIVES AND OF THE STRUCTURE AND FUNCTION OF THE SPACE VEHICLE COULD BE ESSENTIAL TO ADAPTING PLANS AND OBJECTIVES TO UNFORSEEN EVENTS

TECHNOLOGY NEEDS

- IN GENERAL, PAST AI-BASED SYSTEMS HAVE BEEN BRITTLE, NOT WELL INTEGRATED AS COMPONENTS OF BROADER SYSTEMS, ISOLATED FROM CRITICAL DATA OVER WHICH TO REASON, OFTEN BUILT IN AN AD HOC FASHION, AND PRECLUDED FROM REAL-TIME APPLICATIONS DUE TO SEVERE PERFORMANCE CONSTRAINTS
- TOOLS AND TECHNIQUES ARE NEEDED TO SEEMLESSLY INTEGRATE KNOWLEDGE-BASED COMPONENTS INTO A BROADER SOFTWARE SUPPORT ENVIRONMENT
- COMMON LIFE-CYCLE TOOLS AND METHODOLOGY. TECHNIQUES SUPPORTING SOFTWARE RE-USE ARE ESSENTIAL. A UNIFIED VIEW OF DATA, ESPECIALLY SHARED INFORMATION ACROSS MODULES, GEOGRAPHY, AND HARDWARE. RUN TIME SUPPORT FOR HETEROGENEOUS HARDWARE/SOFTWARE, ALONG WITH APPROPRIATE STANDARDS TO MAKE THIS FEASIBLE
- QUALIFIED AND VALIDATED HARDWARE AND SOFTWARE TO SUPPORT AI SOFTWARE COMPONENTS DO NOT EXIST
- A FIRM COMMITTMENT TO INTEGRATE AI INTO REAL WORLD SYSTEMS. RISK CAN BE REDUCED WITH A PHASED, INCREMENTAL APPROACH TO COMPETENCE, BEGINNING WITH DECISION SUPPORT AND WORKING TOWARDS GREATER AUTONOMY

IN-SPACE EXPERIMENTATION NEEDS/VOIDS

- IN A SENSE, AI TECHNOLOGIES ARE ORTHAGONAL TO OUR THEME AREAS, AND COULD BE APPLIED TO MOST OF THE ON-GOING EXPERIMENTS
- VALUABLE INTEGRATION EXPERIENCE COULD BE GAINED BY DEFINING, DESIGNING, BUILDING, AND FLYING AN INTELLIGENT DECISION SUPPORT SYSTEM TO AID CREW MEMBERS IN MANAGING SOME SET OF IN-SPACE EXPERIMENTS. A COMMON FRAMEWORK COULD LIKELY BE APPLIED TO SUPPORT A NUMBER OF SUCH EXPERIMENTS
- SPACE STATION FREEDOM REPRESENTS AN IDEAL OPPORTUNITY TO APPLY INTELLIGENT SYSTEMS IN BOTH CREW DECISION SUPPORT AND SEMI-AUTONOMOUS ROLES
- THE FTS PROVIDES AN OPPORTUNITY TO APPLY THE IDEAS DISCUSSED FOR HUMAN CONTROLLED AND AUTONOMOUS ROBOTICS

SUMMARY & RECOMMENDATIONS

- A RELATIVELY NEW CLASS OF SYSTEM, THE INTELLIGENT SYSTEM, CAN BE EFFECTIVE WHERE CONVENTIONAL OR PURE AI-BASED APPROACHES ARE NOT
- IN THE LONG RUN, INTEGRATED AI WILL BE AN ENABLING TECHNOLOGY FOR AUTONOMOUS, OR VERY COMPLEX MANNED PLANETARY MISSIONS
- IN-SPACE EXPERIMENTS COULD PROVIDE A CRUCIAL, REAL WORLD INTEGRATION OPPORTUNITY

ARTIFICAL INTELLIGENCE

DR. ROBERT CANNON
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INTRODUCTION/BACKGROUND

PROVE NEW CONCEPTS → ADVANCED RESEARCH

- FOR SPACE
- IN SPACE

ADVANCED RESEARCH ↔ BUILD & PROVE NEW TECHNOLOGY

BUILD & PROVE NEW TECHNOLOGY ↔ UPGRADE OPERATIONAL SYSTEMS

TECHNOLOGY NEEDS

- **USER INTERFACE**

  GEOMETRIC
  OBJECT-LEVEL
  SIMPLE

- **MANIPULATOR CONTROL**

  LIGHTWEIGHT
  FLEXIBLE
  QUICK
  PRECISE
  ROBUST
  ADAPTABLE
  GRACEFUL
  WORK FROM A MOVING BASE

TECHNOLOGY NEEDS

o COOPERATION

BETWEEN MANIPULATORS
BETWEEN ROBOTS
BETWEEN ROBOTS AND PEOPLE

o NEW GENERATION OF ENGINEERS

GOOD YOUNG ENGINEERS
GOOD ENGINEERING PROFESSORS/PROGRAMS/SCHOOLS
LOOK AT RADICAL IDEAS

* MEGASYSTEMS
* MICROSYSTEMS

IN-SPACE EXPERIMENTATION NEEDS

- o ARTIFICIAL INTELLIGENCE NEEDS FLIGHT TESTING ONLY IN CONJUNCTION WITH DEPENDENT TECHNOLOGY, e.g. ROBOTICS

- o NEED TO GET NEW GENERATION OF YOUNG ENGINEERS INVOLVED IN FLIGHT EXPERIMENTS

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AUTOMATION AND ROBOTICS CRITICAL TECHNOLOGY REQUIREMENTS

ANTAL K. BEJCZY
JET PROPULSION LABORATORY

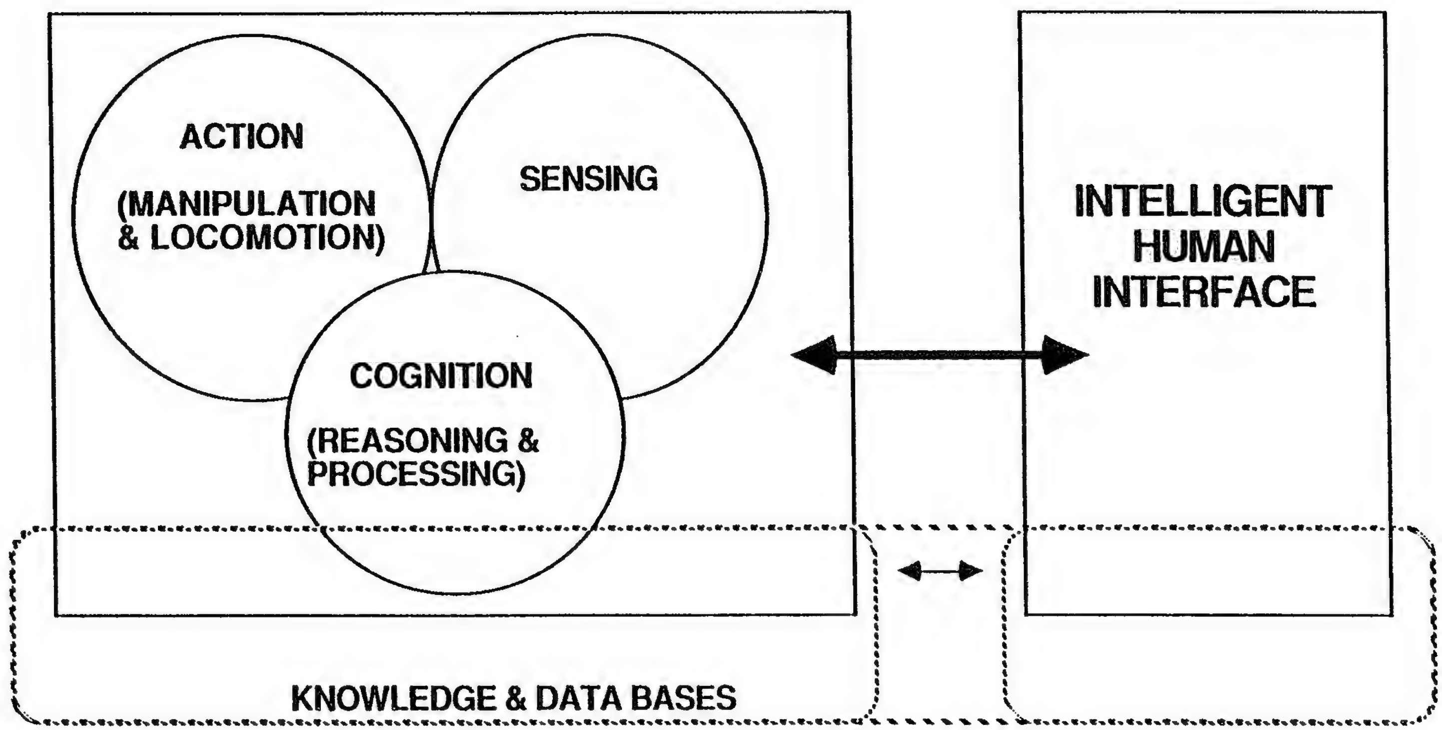
TARGET NASA MISSIONS

- o STS
- o GREAT OBSERVATORIES
    - HST
    - GRO
    - AXAF
    - SIRTF
- o SSFP
- o FREE FLYERS (including POP)
- o LUNAR OUTPOST
- o MARS EXPLORATION

USER NEED TASK DRIVERS

- IN-SPACE ASSEMBLY
- MATERIALS PROCESSING
- MATERIALS HANDLING
- SYSTEMS MAINTENANCE AND OPERATIONS
- SATELLITE SERVICING
- EXPLORATION

INTEGRATED APPROACH FOR A & R ON A MULTI-DISCIPLINARY BASE



GENERAL THRUST

AUGMENT AND ENHANCE HUMAN RESOURCES/CAPABILITIES BY ENABLING HUMAN CONTROL OF COMPLEX SYSTEMS AT HIGHER & HIGHER LEVELS WHILE RETAINING CAPABILITY TO ENTER CONTROLLING PROCESS AT MULTIPLE LEVELS

SPACE ROBOTICS TASK DOMAINS

o WIDE RANGE OF OPERATING SCALES

- LARGE / HEAVY (e.g. SATELLITE, PAYLOAD MANIPULATION)
- SMALL / LIGHT (e.g. INSTRUMENT ADJUSTMENT, MATERIALS PROCESSING)

o MECHANICAL COUPLING ENVIRONMENT

- RIGID BASE
- FLEXIBILY COUPLED
- FREE FLYING

o VARYING ILLUMINATION ENVIRONMENT

SPACE ROBOTICS TECHNOLOGY NEEDS

- ROBUST AND SAFE MANIPULATION / LOCOMOTION
  - CONTROL LAWS
  - COLLISION AVOIDANCE
  - COMPLIANCE (ACTIVE OR PASSIVE)
  - USE OF TASK MODELS OR ADAPTIVE CONTROL
  - LOCAL AUTONOMY BASED ON SENSING
  - DYNAMICS OF COUPLING TO PLATFORM
- FAULT TOLERANT HARDWARE / SOFTWARE ARCHITECTURES
  - MECHANISMS
  - ACTUATORS
  - SENSORS
  - SENSOR / CONTROL PROCESSORS
  - FAILURE DETECTION, IDENTIFICATION, AND RECOVERY

TELEOPERATIONS, DOMAINS AND NEEDS

- SUPERVISORY CONTROL FOR TELEROBOTIC OPERATIONS IN SPACE
  - DYNAMIC TASK CONTROL
  - ENHANCED VISUAL DISPLAYS WITH COMPUTATION (E.G. COLLISION AVOIDANCE)
  - BIDIRECTIONAL M / M INTERFACES WITH HIERARCHICAL OBJECT-ORIENTED ARCHITECTURE AND MULTI-MODE CAPABILITIES
  - MODELS FOR TELEROBOT AND ITS ACTIONS

TELEOPERATIONS, DOMAINS AND NEEDS
(Cont.)

- CONTROL LOCATION
  - ON ORBIT
    - OPERATOR WITH FORCE FEEDBACK
    - ROBOT ARM - VEHICLE INTERACTION
  - ON GROUND
    - COMMUNICATION DELAY / BANDWIDTH
    - INTERACTING WITH MICROGRAVITY
- HIGH DEGREE-OF-FREEDOM SYSTEMS
  - REDUNDANT ARMS
  - MULTIPLE ARMS
  - DEXTROUS END EFFECTORS AND TOOLS

ARTIFICIAL INTELLIGENCE TASK DOMAINS

- FAULT PROCESSING
  - AUTOMATED FAULT DETECTION, ISOLATION, RECOVERY / RECONFIGURATION
  - DIAGNOSIS OF UNANTICIPATED, MULTIPLE FAULTS
  - CONTINGENCY REPLANNING
- LARGE INPUT / OUTPUT SYSTEMS
  - SENSOR INTERPRETATION / FUSION
  - REAL-TIME IMAGE PROCESSING
  - SPEECH RECOGNITION AND SYNTHESIS

ARTIFICIAL INTELLIGENCE TECHNOLOGY NEEDS

- INTEGRATED, REAL-TIME, FAULT-TOLERANT, COOPERATIVE INTELLIGENT SYSTEMS
  - PARALLEL, INTEGRATED NUMERIC / SYMBOLIC PROCESSING
  - ADVANCED, INTELLIGENT OPERATING SYSTEM
  - LARGE, DYNAMIC, DISTRIBUTED KNOWLEDGE BASE
  - INTEGRATION OF DATA AND MODEL INFORMATION
  - LAYERED, TRANSPARENT SOFTWARE
- INTELLIGENT HUMAN INTERFACES

6.0 SENSORS AND INFORMATION SYSTEMS

SENSORS AND INFORMATION SYSTEMS BACKGROUND AND OBJECTIVES

MARTIN M. SOKOLOSKI
NASA HEADQUARTERS
and
JOHN DALTON
GODDARD SPACE FLIGHT CENTER

THEME SESSION OBJECTIVES

PURPOSE

IDENTIFY & PRIORITIZE TECHNOLOGIES FOR SENSORS, COMMUNICATIONS, AND INFORMATION SYSTEMS WHICH

- ARE CRITICAL FOR FUTURE U.S. SPACE PROGRAMS
- REQUIRE IN-SPACE TESTING AND VALIDATION

PRODUCT

HIGH PRIORITY TECHNOLOGIES AND RATIONALE FOR IN-SPACE EXPERIMENTATION:

- TECHNOLOGY NEED
- IMPORTANCE TO SPACE MISSIONS
- IN-SPACE TESTING REQUIRED

THEME DESCRIPTION

SENSORS

- DEVICES & OPTICS
- LASERS
- PRECISION POINTING
- THERMAL MANAGEMENT & CRYOGENICS

COMMUNICATIONS

- OPTICAL & MICROWAVE
- POINTING, TRACKING, & ACQUISITION

INFORMATION SYSTEMS

- SPACE QUALIFIED PROCESSORS , STORAGE & COMPONENTS
- IMAGE & SIGNAL PROCESSORS
- DATA NETWORKS & TELEMETRY SYSTEMS
- AUTOMATED SYSTEMS

CRITERIA FOR PRIORITIZATION

1. CRITICALITY OF TECHNOLOGY IN ENABLING FUTURE U.S. SPACE MISSIONS

2. POTENTIAL OF TECHNOLOGY FOR REDUCING COST (DEVELOPMENT, OPERATIONS, OR LIFE CYCLE)

3. DEGREE TO WHICH TECHNOLOGY HAS BROAD APPLICATION TOA VARIETY OF SPACE MISSIONS

4. REQUIREMENT FOR IN-SPACE VALIDATION TO EXPERIMENT WITH OR VERIFY PERFORMANCE IN MICRO-GRAVITY / THERMAL / RADIATION ENVIRONMENT OR TO REDUCE RISK FOR OPERATIONAL APPLICATIONS

6.1 SENSORS

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IN-SPACE EXPERIMENTS IN REMOTE SENSING SYSTEMS

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INTRODUCTION/BACKGROUND

- NASA R&D PROGRAMS
  - Detector Arrays
    - Superconducting Bolometer Arrays
    - Impurity Band Conduction Detectors
    - III-V Material Arrays
    - Superlattice Detectors
  - Heterodyne Systems
    - Local Oscillators
      - Millimeter
      - Submillimeter
      - FIR
    - Mixers
    - Antennas (Radiometry)
      - 4M f>100GHz
      - 15-20M f<100GHz
    - Quasi-optics (Submillimeter)

INTRODUCTION/BACKGROUND

- NASA R&D PROGRAMS (Continued)
  - DIAL/LIDAR
    - Lasers
      - Wavelength
      - Semiconductor Diode Array Pumps
      - CO_2 Systems
      - Solid State Lasers (amps)
      - All Solid State Systems
    - Detectors
  - Coolers
    - Single Stage
      - Pulse Tube
      - Mechanical
      - Dilution
      - Flux Compression
      - ADM
    - Multi-Stage

IN-SPACE EXPERIMENTATION NEEDS/VOIDS

- DETECTORS
  - Radiation Effects on Arrays
  - Effects of Contaminants on Response of Detectors
  - System Demonstration under Low Background Conditions
  - Interaction of Coolers and Detector Systems
  - Retrofit on In-Reach LITE System with New Detector Arrays & Refly
  - Maintenance of Optical Surface Quality in Space with In-situ Cleaning Demonstration

IN-SPACE EXPERIMENTATION NEEDS/VOIDS (CONT'D)

- HETERODYNE SYSTEMS
  - UV, Protons, and Electron Radiation Effects on Components & Systems
  - Effect of Contaminants on System Performance
  - Modify LITE Experiment for Single or Dual Channel for IR Radiometer for OH Measurement Demonstration
  - Space Test of Large Unfilled Synthetic Aperture Radiometer (Requires Large Structure ~20 M Arms) for Proof of Concept
  - Space Test of 30 and 118 Micrometer Heterodyne Imaging Spectrometer

IN-SPACE EXPERIMENTATION NEEDS/VOIDS (CONT'D)

- DIAL/LIDAR SYSTEMS
  - Retrofit LITE Platform with Tuneable Solid State Laser for DIAL Measurements Demo
  - Retrofit 2 Micrometer Doppler Wind Shear Detector on LITE
  - Demonstrate In-Space Operation of Semiconductor Diode Array Pumps
  - Test of Picosecond Laser Ranging and Altimeter System
  - In-Space Test of Laser System Stability

IN-SPACE EXPERIMENTATION NEEDS/VOIDS (CONT'D)

- COOLER SYSTEMS
  - Microgravity Test of Liquid/Vapor Phase Separation in Joule-Thomson Refrigerators
  - Microgravity Test of 3He/4He Dilution Refrigerator Systems:
    - JPL System Concept
    - ARC System Concept
    - MSFC System Concept
  - Extended Microgravity & Vacuum Test of Mechanical Coolers (10 kelvin and Above)
  - Proof of Principle of Microgravity Operation of Subkelvin Coolers

SUMMARY/RECOMMENDATIONS

- REQUIREMENTS FOR SENSOR SYSTEM IN-SPACE EXPERIMENTS
  - Test of Operation in Space Radiation Environment
  - Functioning in Micro- or 0-g Environment
  - Operation in Vacuum
  - Survive Launch
  - Survive Shuttle Contamination

IN-SPACE SENSOR TECHNOLOGY EXPERIMENTS

E. David Hinkley
Hughes Aircraft Company
El Segundo, California

HUGHES

PURPOSE OF IN-SPACE SENSOR TECHNOLOGY EXPERIMENTS

TO DEMONSTRATE:

1. FEASIBILITY
2. RELIABILITY
3. ENVIRONMENTAL COMPATIBILITY

HUGHES

UNIQUENESS OF SPACE ENVIRONMENT FOR SENSOR SYSTEMS

- NEAR-ZERO GRAVITY
- NONSTATIONARY PLATFORM
- SPECIAL SPACECRAFT ATMOSPHERES
- CONTAMINATION-INDUCED PERFORMANCE DEGRADATION
- STRONG RADIATION FLUX (UV, VIS, GAMMA)
- IN-VACUO WAVE PROPAGATION

HUGHES

CATEGORIES FOR IN-SPACE SENSOR TECHNOLOGY EXPERIMENTS

1. THERMAL MANAGEMENT, CRYOGENICS
2. OPTICS CONTAMINATION/DECONTAMINATION
3. PRECISION POINTING & TRACKING
4. LASER OPERATION

HUGHES

SPACE APPLICATIONS
Thermal Management, Cryogenics

1. SENSOR/ELECTRONICS CRYOCOOLING
2. HEAT SWITCH FOR REDUNDANT CRYOCOOLER
3. WASTE HEAT TRANSFER TO RADIATOR
4. OPTICS CRYOCOOLING

HUGHES

SPACE APPLICATIONS
Optics Contamination/Decontamination

1. OPTICS FOR UV, VIS, IR ASTRONOMY

2. CRYOCOOLED SENSORS & ELECTRONICS

HUGHES

SPACE APPLICATIONS
Precision Pointing & Tracking

1. LASER REMOTE SENSING
2. HIGH-RESOLUTION ASTRONOMY
3. FAINT-TARGET ASTRONOMY (LONG INTEGRATION)
4. EARTH OBSERVATIONS FROM GEOSYNCH ORBIT
5. DEEP-SPACE OPTICAL COMMUNICATION

HUGHES

SPACE APPLICATIONS
Lasers

1. WEATHER-RELATED MEASUREMENTS
2. ATMOSPHERIC CHEMISTRY MEASUREMENTS
3. HIGH-SPEED OPTICAL COMMUNICATIONS
4. IN-SPACE MANUFACTURING

LIDAR/LASER SENSORS

DR. DENIS KILLINGER
UNIVERSITY OF SOUTH FLORDIA

Table II. Selected List of Atmospheric Constituents and Parameters Measured by Lidar

Constituents	Laser Type	Accuracy*	Lidar Type	Range*
Dust, Clouds Volcanic Ash Smoke Plumes	Ruby, Nd:YAG	1-10%	Atmospheric Backscatter	10-50 Km
H_2O, O_3, SO_2 NO, NO_2, N_2O C_2H_2, CH_4, HCl, CO, Hg	Dye, CO_2, OPO, Excimer Co:MgF_2	Variable, 1 ppb to 100 ppm	DIAL, Raman	1-5 Km
OH, Na, K, Li, Ca, Ca^+	Dye	$10^2 - 10^7$ atoms/cc	Fluorescence	1-90 Km
Parameters				
Temperature, Pressure	Dye, Nd:YAG	1 K^o 5 mbar	DIAL, Raman	1-30 Km
Wind Speed	CO_2	0.5 m/s	Doppler	15 Km

* Accuracy and Ranges given are typical values and depend upon individual lidar measurements.

SPACEBORNE OPPORTUNITIES

- Global Laser Remote Sensing

  1. Detection of $[H_2O]$, $[CO_2]$, $[O_3]$
     Temperature, wind speed from space;
     LITE, LASA, EAGLE

  2. Range/Altimeter for Surface and Ice Pack
     Profile, Fault Line Movement

- In-Situ Sensors

  - High Altitude (In-Situ) Sensors
    for Trace Gas Contamination

- Unique Spaceborne Problem Areas
  - Power (<10 kw, Eff. > 5%)
    Heat Dissipation (Primary, A/O Modulators)
  - Weight (< 2000 kg)
  - Zero Gravity (Liquids/Dye Lasers, Cooling)
  - Size
  - Lifetime (Consumable, Laser H.V.)
  - Eye Safety ($\lambda > 1.4\ \mu m$)

- <u>Critical Technolgoy</u>

1) Laser Development

  - Diode Laser Pumping of Existing Lasers

  - New Tunable (MID-IR) Laser Sources

Ho:YAG	Nd:Glass/Raman Shift
Ti:Sapphire	Single-Frequency (Nd, etc.)
Er:YAG/OPO	Local Oscillator (cw/Rapid Wide Tunability)

  - Lifetime Issues

    CO_2/Catalyst

    H.V./Electrodes

2) <u>LIDAR Deployment</u>

LITE (Laser In-Space Technology Exp.)

- Nd:Y AG (2x, 3x)

  1st Spaceborne LIDAR

- Phase II; Ti:Sapphire

LASA/EOS

- LIDAR (use to correct passive)
- DIAL
- Altimetry

LAWS (WINDSAT)

- CO_2/Doppler (Lifetime)
- Nd:YAG (L.O. Tracking)

Ozone (Excimer/Raman Shift)

Pointing/Tracking Accuracy

- Small Footprint (more severe than Radar)

  (Laser/Telescope Overlap)

- Push-Broom Scan
- Effect of Atmospheric Turbulence

  (Motion /Tracking)

3) Laser Sensor

Absorption/Fluroescence Sensors

(Trace Species In-Situ)

- Fiber/Optical Coupling

- Tunable Microlaser Sensors

- Road Map (LIDAR/SENSORS)

LIDAR Development

1. Space Shuttle Test of Simple LIDAR (Nd:YAG): LITE
2. Spaceborne LIDAR/Diode Pumped Nd:YAG
   - Direct & Coherent Detection (Limited power)
3. Coherent Doppler (Nd & CO_2)
   - L.O. Tracking
4. Atmospheric Density/H_2O for Passive Corrections
5. Altimeter/Surface Profiler LIDAR

LASER Development

1. Long-Life Nd:YAG
2. Diode-Laser Pumped Nd:YAG
3. Ho:YAG
4. Tunable $Ti:Al_2O_3$
5. Tunable Local Oscillator

6.2 COMMUNICATIONS

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IN-SPACE EXPERIMENTS IN COMMUNICATION SYSTEMS

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INTRODUCTION/BACKGROUND

- Optical Communication System Elements
  - Lasers & Laser Systems
  - Modulation Techniques
  - Detection (Coherent, Non-coherent)
  - Optics
  - Electronics
- Space Qualification
  - Space Radiation Environment/Energetic Particles
  - Vacuum
  - Microgravity
  - Spacecraft Charging and Outgassing
- Laser Systems Not Space Demonstrated

INTRODUCTION/BACKGROUND (CONT'D)

- NASA R&D Programs
  - Laser Sources
    - AlGaAs
    - Semiconductor Diode Laser Array Pumped Solid State Laser Rods & Slabs
  - Detection
    - Coherent
    - Non-coherent
  - Modulation Techniques
  - Electronics

MISSION APPLICATIONS

- Mission to Planet Earth
  - GEO/GEO for Geoplat
  - GEO/LEO for Geoplat & Eos
  - GEO/Earth
- Planetary
  - Mars Rover
  - Cassini
  - Others
- Solar Physics
  - Star Probe (Enabling)

TECHNOLOGY NEEDS

- Free-Space Optical Communications "Revolutionary" Technology
- Breadboard In-space Demo Needed
- Component Space Qualification
  - Laser & Laser Power
  - Pointing & Control (Closed and Open Loop)
  - Modulation Rate Demo
  - Demo of Space/Ground Link
  - Demo Space/Space Link

IN-SPACE EXPERIMENTATION NEEDS/VOIDS

- In-space Breadboard Demo of "Revolutionary" Technology
  - Space-Space
  - Space/Ground
  - Closed & Open Loop Acquisition
  - Coherent/Non-coherent Links

SPACE LASER COMMUNICATION EXPERIMENTS

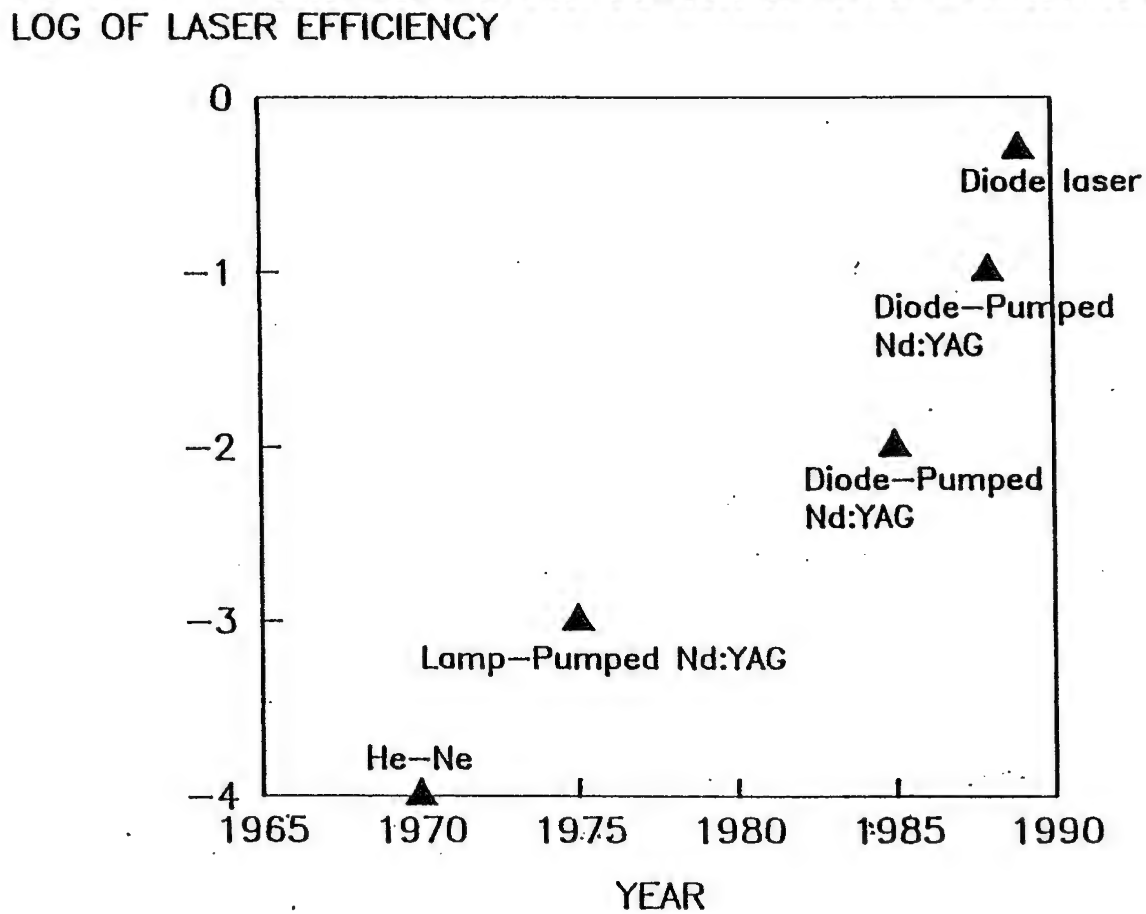
M. ROSS

LASER DATA TECHNOLOGY, INC.

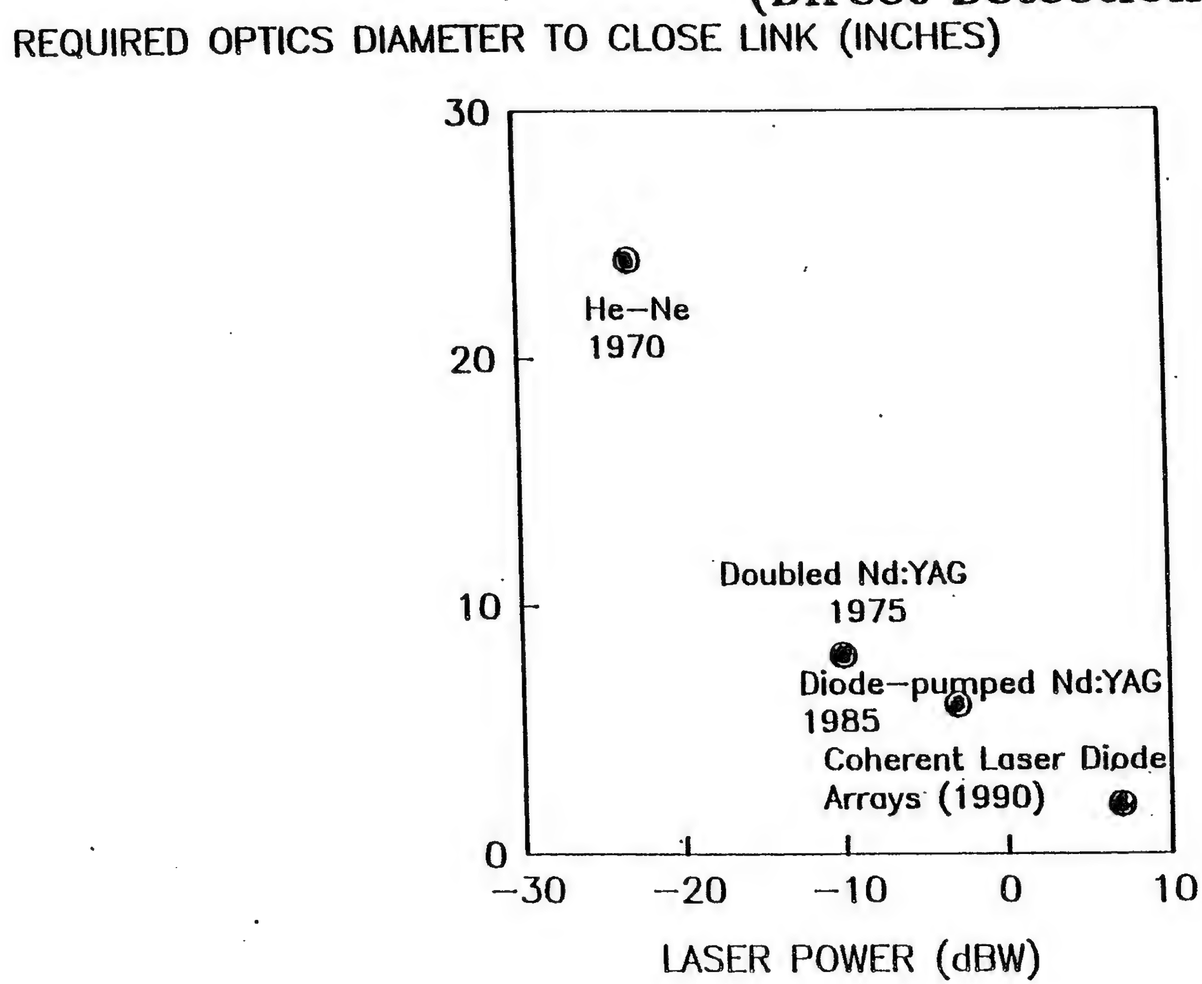
SEMICONDUCTOR LASER BREAKTHROUGH

- HIGH EFFICIENCY
  - GREATER THAN 50% ACHIEVED
- UNIFORMITY ACHIEVED
  - ARRAYS FEASIBLE
- MULTI—WATT OUTPUTS ACHIEVED

EFFICIENCY TRENDS FOR VISIBLE AND NEAR IR LASERS



LASER POWER/OPTICS SIZE TREND FOR SPACE LASERCOM (Direct Detection)



TECHNOLOGY TREND

Photonics Capabilities Advancing Rapidly

Greater Solid State Laser Power Acheivable at Higher Efficiency and Lower Cost

Enables Use of More Tolerant Designs in Rest of System

- –Smaller, Less Precise Optics
- –Easier Tracking Systems
- –Less Integration and Test Costs

Enables Lower Weight, Lower Power, Lower Cost Laser Communication Systems

- –100lb, 100 watt Systems Will Become Acheivable for Long–Distance Satellite–to–Satellite Links

SUMMARY

- POTENTIAL OF LASER COMMUNICATIONS UNTAPPED
- HISTORY OF SPACE LASERCOM EXPERIMENTS
  - MANY STARTS, NO FINISHES
  - LACK OF GOVERNMENT COMMITMENT TO FOLLOW THRU
- TECHNOLOGY STATUS
  - ABLE TO SUPPORT EXPERIMENTS
- SPACE EXPERIMENT NEEDED FOR VALIDIDATION
  - HARDWARE
  - RELIABILITY
  - CONCEPTS

SPACE LASERCOM EXPERIMENTS

LINK	DATA RATES	NOTES
ONE-TO-ONE	1 to 5 Mbps	SCIENTIFIC PAYLOADS; IMAGES; SENSOR DATA
	> 200 Mbps	REAL TIME HIGH RESOLUTION IMAGERY
MANY-TO-ONE	1 to 5 Mbps	MULTIPLE ACCESS
ONE-TO-MANY	< 20 Kbps	COMMAND CONTROL

RECOMMENDATIONS

- DON'T TRY AND DEMONSTRATE TOO MUCH
- NASA SPONSOR ONE LOW-COST SIMPLE SPACE EXPERIMENT THAT
  - VALIDATES CONCEPT
  - DEMONSTRATE COMPONENT RELIABILITY
  - DEMONSTRATES BASIC SUBSYSTEMS SUCH AS
    - ACQUISITION
    - TRACKING
    - LASER TRANSMITTER
    - LASER RECEIVER
- RANGE NOT CRITICAL; COULD BE SHORT RANGE

  EXAMPLE: SHUTTLE TO FREE FLYER

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COHERENT OPTICAL INTERSATELLITE CROSSLINK SYSTEMS

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LASERCOM CROSSLINK TECHNOLOGY

- CANDIDATE SYSTEM TECHNOLOGIES
  - DIRECT DETECTION (Incoherent)
  - HETERODYNE (Coherent)
- HETERODYNE RECEIVER 15 dB MORE SENSITIVE THAN DIRECT DETECTION
- HIGH ANTI-JAM CAPABILITY
- SMALLER APERTURE ALLOWS EASIER SPACECRAFT INTEGRATION
- USE OF HIGH EFFICIENCY (15%) GaAlAs SEMICONDUCTOR LASERS
- LINCOLN LABORATORY LASER INTERSATELLITE TRANSMISSION EXPERIMENT (LITE)

LASER CHARACTERISTICS FOR COHERENT SYSTEMS APPLICATIONS

- HIGH OUTPUT POWER
  - SIZE, WEIGHT, POINTING, MARGIN
- SINGLE SPATIAL MODE
  - USEFUL POWER IN FAR FIELD
- SINGLE FREQUENCY
  - HETERODYNE RECEIVER
- TUNABLE WAVELENGTH
  - WAVELENGTH MATCH, TRACKING
- DIRECT MODULATION
  - EQUALIZABLE FM TRANSFER FUNCTION
- NARROW LINEWIDTH
  - SPECTRAL SPREADING IMPACT ON BER
- STABLE, RELIABLE LIFE
  - $>$50,000 hr GOAL

OPTICAL/MECHANICAL/THERMAL DESIGN ISSUES

- OPTICAL DESIGN
  - MAINTAIN THROUGHPUT, WAVEFRONT QUALITY
  - PROVIDE ACCURATE POINTING
- MECHANICAL DESIGN
  - PROVIDE STIFFNESS, STABILITY TO MAINTAIN OPTICAL ALIGNMENT, POINTING ACCURACY
  - ISOLATE AGAINST SPACECRAFT DISTURBANCES
- THERMAL DESIGN
  - MINIMIZE AND STABILIZE TEMPERATURE GRADIENTS UNDER VARYING THERMAL SCENARIOS

HETERODYNE RECEIVER TECHNOLOGY

- LOW-NOISE/WIDEBAND FRONT END
  - NEAR-QUANTUM-LIMITED 1 GHz FRONT END DEMONSTRATED (LITE)
  - FURTHER DEVELOPMENT REQUIRED TO EXTEND BANDWIDTH AT QUANTUM LIMIT
- FREQUENCY-LOCKING
  - DONE ROUTINELY FOR FSK (LITE)
- PHASE-LOCKING
  - DIFFICULT WITH PRESENT LASER LINEWIDTHS

SPATIAL ACQUISITION

- LARGE INITIAL POINTING UNCERTAINTY
  - DOMINATED BY SPACECRAFT ATTITUDE CONTROL ERROR ($\sim$ 1 mRAD Typical)
  - SMALL COMMUNICATIONS BEAMWIDTH (4 μrad In LITE)
- SEARCH OVER MANY SPATIAL "CELLS" REQUIRED
- CCD TECHNOLOGY WILL PERMIT RAPID ACQUISITION (Few Seconds)

CONCLUSIONS

- COHERENT TECHNOLOGY IS READY FOR SPACE CROSSLINK APPLICATIONS
- IT OFFERS SMALL APERTURE SIZE, MODEST WEIGHT AND POWER
- WITH COMMERCIALLY AVAILABLE COMPONENTS, SEVERAL HUNDRED Mbps CAN BE SUPPORTED WITH 20 cm TELESCOPES

CRITICAL TECHNOLOGY DEVELOPMENT NEEDS FOR SPACE LASER COMMUNICATION SYSTEMS

- ASSESSMENT OF STATE-OF-THE-ART TECHNOLOGY
- EXAMINE INTERPLAY BETWEEN TECHNOLOGY AND SYSTEM DESIGNS
- SOUND FLEXIBLE DESIGN
- ON-ORBIT DEMONSTRATION AND EXPERIMENTATION

    1. SPATIAL ACQ / TRACK EXECUTION AND EXPERIMENTATION
    2. OPTICAL / MECHANICAL / THERMAL DESIGN VERIFICATION
    3. USE OF EXPERIENCE GAINED FOR THE DESIGN OF OPERATIONAL SYSTEMS

6.3 INFORMATION SYSTEMS

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IN-SPACE EXPERIMENTS IN INFORMATION SYSTEMS

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INTRODUCTION/BACKGROUND

o INFORMATION SYSTEMS ELEMENTS:

- SPACE-QUALIFIED PROCESSOR SYSTEMS AND COMPONENTS
- HIGH-SPEED IMAGE AND SIGNAL PROCESSING
- HIGH CAPACITY STORAGE
- ON-BOARD LOCAL AREA NETWORKS AND DATA HANDLING SUBSYSTEMS
- AUTOMATED SYSTEMS AND FAULT TOLERANT SYSTEMS

CURRENT NASA CAPABILITY

- PROCESSORS:

  NSSC-1, SHUTTLE COMPUTERS, 1750A PROCESSORS, HARRIS 80C86 (MARS OBSERVER)

  PLANNED : SPACE STATION FREEDOM INTEL/IBM 80386, CRAF/CASSINI SANDIA 32016

- IMAGE PROCESSING:

  NONE

- HIGH CAPACITY STORAGE:

  LONGITUDINAL TAPE RECORDERS, VHS-BASED HELICAL SCAN(MANNED MISSIONS)

- ON-BOARD DATA HANDLING:

  MISSION-UNIQUE

- AUTOMATED SYSTEMS:

  PRIMARILY LIMITED TO PROCESS CONTROL PROCEDURES, WITH SOME AUTOMATED FAULT PROTECTION

INTRODUCTION/BACKGROUND (CONTINUED)

NASA R&D PROGRAMS

- <u>PROCESSORS</u>:
  - FAULT TOLERANT MULTIPROCESSOR SYSTEM (LaRC, JPL)
  - FLIGHT SYMBOLIC PROCESSOR WITH RH32 NUMERIC PROCESSOR (ARC)
- <u>IMAGE PROCESSING</u>:
  - GaAs BIT SLICE PROCESSOR PIPELINE (GSFC)
  - MULTISPECTRAL IMAGE COMPRESSION/PROCESSING (JPL, GSFC)
- <u>HIGH CAPACITY STORAGE</u>:
  - SPACE OPTICAL DISK RECORDER - 160 Gbit capacity, 300 Mbps (LaRC)
  - ROTARY HEAD TAPE RECORDER HEAD LIFE TESTING (GSFC)
  - MEDIUM RATE (20 Mbps) LONGITUDINAL RECORDER (GSFC)
- <u>ON-BOARD DATA HANDLING</u>:
  - FIBER OPTIC TRANSCEIVERS (LaRC)
  - HIGH RATE ARCHITECTURE (GSFC)
  - CCSDS STANDARD FORMAT DATA HANDLING SYSTEMS (GSFC)
- <u>AUTOMATED SYSTEMS</u>:
  - SYSTEMS AUTONOMY DEMONSTRATIONS FOR SPACE STATION FREEDOM (POWER AND THERMAL SYSTEM CONTROL) - (ARC, JSC, LeRC)

MISSION APPLICATIONS

- ON-BOARD SYSTEM AND SENSOR CONTROL AND DATA PROCESSING APPLICATIONS GENERALLY APPLICABLE TO MOST SPACE MISSIONS:
  - *INTELLIGENT SENSORS* FOR LONG TERM MONITORING OF PHENOMENA AND FOR ADAPTIVE OBSERVATION OF SCIENTIFICALLY INTERESTING EVENTS
  - ON-BOARD SENSOR *CALIBRATION AND PROCESSING*
  - ON-BOARD *CONTROL* OF COORDINATED MULTI-SENSOR OBSERVATIONS
  - ON-BOARD *FAULT DETECTION AND RECONFIGURATION* OF SPACECRAFT SYSTEMS
  - *COMPRESSION*, BUFFERING, AND ON-BOARD PROCESSING FOR HIGH RATE IMAGING INSTRUMENTS
  - DATA DRIVEN *TELEMETRY SYSTEMS* (USING PACKET TELEMETRY STANDARDS)
  - ON-BOARD *RESOURCE CONTROL* TO IMPROVE RESPONSIVENESS OF SCIENCE OPERATIONS

- SUPPORTING PROCESSOR TECHNOLOGY FOR ROBOTICS:
  - TASK PLANNING
  - SENSING AND REACTIVE CONTROL
  - MACHINE VISION

TECHNOLOGY NEEDS

o SPACE-QUALIFIED PROCESSORS:

- HIGHER PERFORMANCE 32-BIT PROCESSORS TO SUPPORT COMPLEX CONTROL OPERATIONS
- PROCESSOR MEMORY CAPACITY (4 TO 32 MBYTES):
  - REDUCE FLIGHT SOFTWARE DEVELOPMENT COST
  - SUPPORT ON-BOARD SENSOR CALIBRATION AND DATA COMPRESSION
  - REDUCE TDRS CONTACT TIME REQUIRED FOR PROCESSOR LOADS

o IMAGE AND SIGNAL PROCESSING:

- IMAGE COMPRESSION DEVICES TO REDUCE TELEMETRY BANDWIDTH
- PROCESSORS TO SUPPORT FEATURE AND INFORMATION EXTRACTION
- COMPRESSION OF TIME SERIES OF HIGH RESOLUTION IMAGES (MICRO GRAVITY EXPERIMENTS)

o HIGH CAPACITY STORAGE:

- DIRECT ACCESS STORAGE (50 MBYTES TO 10 GBYTES)

  ON-BOARD MANAGEMENT AND PRIORITY PLAYBACK OF ENGINEERING DATA, CONTROL PROGRAM LOADS, IMAGE STORAGE FOR NEAR-REAL TIME PROCESSING
- HIGH RATE STORAGE (250 MBYTES @ 20 Mbps to 31GBYTES @ 300 Mbps)

  LINK BUFFERING OF IMAGING SENSORS

TECHNOLOGY NEEDS (CONTINUED)

o <u>NETWORKS AND DATA HANDLING SYSTEMS</u>:

- FAULT-TOLERANT, ADAPTABLE ON-BOARD DATA SYSTEMS THAT ARE OPERABLE (UPGRADABLE, MAINTAINABLE) ON-LINE FROM GROUND CONTROL CENTERS
- PACKET TELEMETRY INTERFACES
- SYSTEM CONTROL INTERFACES FOR RESOURCE ENVELOPE ENFORCEMENT

o <u>AUTOMATED SYSTEMS</u>:

- REAL-TIME EXPERT SYSTEMS FOR SENSOR AND SYSTEM CONTROL
- ON-BOARD RESOURCE MANAGEMENT AND CONTROL

ISSUE

LARGE GAP EXISTS BETWEEN PERFORMANCE CAPABILITY OF GROUND-BASED INFORMATION SYSTEMS AND SPACE QUALIFIED SYSTEMS:

- SPACE ENVIRONMENT REQUIREMENTS: RADIATION, THERMAL, LAUNCH STRESS
- POWER AND WEIGHT CONSTRAINTS

ADVANCED MISSION CONCEPTS TEND TO BE BASED ON TECHNOLOGY CAPABILITY OF GROUND SYSTEMS, AND MUST BE SUBSTANTIALLY DESCOPED TO BE IMPLEMENTABLE IN PROVEN FLIGHT TECHNOLOGY.

IN-SPACE EXPERIMENTATION NEEDS/VOIDS

o PROCESSORS:

- DEMONSTRATE SPACE-QUALIFIED, FAULT TOLERANT PROCESSORS AND MEMORY SYSTEMS
  - WITH ACCEPTABLE POWER AND WEIGHT CHARACTERISTICS
  - SUFFICIENT SPACE ENVIRONMENT OPERATION TO VERIFY PERFORMANCE

o IMAGE PROCESSORS:

- DEMONSTRATE SPACE-QUALIFIED PROCESSORS FOR HIGH RATE LOSSLESS IMAGE COMPRESSION
- DEMONSTRATE SPACE-QUALIFIED PROCESSORS PROGRAMMABLE FOR MULTISPECTRAL IMAGE FEATURE EXTRACTION

o STORAGE:

- DEMONSTRATE LAUNCH SURVIVAL AND IN-SPACE OPERATION OF MOVING MEDIA STORAGE DEVICES
- LONG DURATION EXPOSURE OF MATERIAL AND COMPONENTS TO RADIATION ENVIRONMENTS (LASERS, WRITE-ONCE AND ERASABLE MEDIA, ETC.)

o NETWORKS AND DATA HANDLING SYSTEMS:

- DEMONSTRATE SOFTWARE AND SYSTEM RECONFIGURATION WHILE MAINTAINING RELIABLE OPERATIONS
- DEMONSTRATE SPACE-QUALIFIED COMPONENTS FOR TELEMETRY GENERATION AND HANDLING SUPPORTING CCSDS PACKET TELEMETRY STANDARDS

o AUTOMATED SYSTEMS:

- DEMONSTRATE IN-SPACE OPERATION OF AUTOMATED EXPERIMENT AND SUBSYSTEM OPERATIONS
- DEMONSTRATE OPERATION OF AUTOMATED RESOURCE MANAGEMENT SUBSYSTEMS

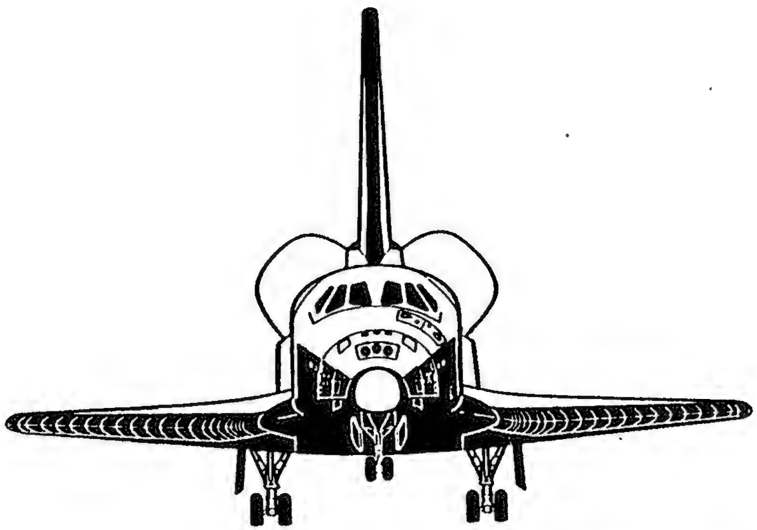
  (E.G., RESOURCE ENVELOPE ALLOCATION, RESOURCE CHECKING, COMMAND CHECKING, INTERLOCKS)

SUMMARY/RECOMMENDATIONS

- REQUIREMENTS FOR INFORMATION SYSTEMS IN-SPACE EXPERIMENTS
  - SUCCESSFUL LONG DURATION EXPOSURE TO AND OPERATION IN RADIATION ENVIRONMENT
  - ACCEPTABLY LOW POWER AND WEIGHT REQUIREMENTS
  - LAUNCH SURVIVAL AND ZERO-G OPERATION PRIMARILY FOR MOVING MEDIA STORAGE DEVICES
  - SMART SENSOR SYSTEMS TESTED IN OBSERVATIONS FROM SPACE
  - AUTONOMOUS SYSTEMS: SUFFICIENT TESTING TO ELIMINATE PERCEIVED RISK

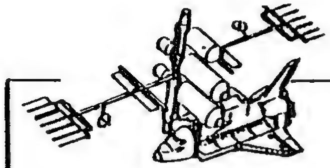
INFORMATION SYSTEM PANEL
DMS PERSPECTIVES
DECEMBER '88

GEORGE NOSSAMAN



space systems

IBM
Federal Systems Division
3700 Bay Area Blvd., Houston 77058



RATIONALE FOR IN-SPACE TECHNOLOGY EXPERIMENTS

"DMS PERSPECTIVES"

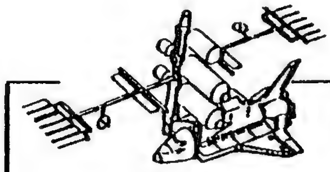
- SPACE TESTING GENERALLY EXPENSIVE

- ENVIRONMENT CAN NOT BE ACCURATELY SIMULATED IN GROUND LABS

GROUND-SUFFICIENT	IN-SPACE
THERMAL	ZERO-G
VACUUM	RADIATION (COMPLETE)
EMC	MULTIPLE EFFECTS
VIBRATION	
RADIATION (PARTIAL)	

- CONFIDENCE - BUILDING
  - ON-ORBIT TESTING RAISES CONFIDENCE IN SYSTEM APPROACH
  - DOES NOT COVER ALL PROBLEM AREAS

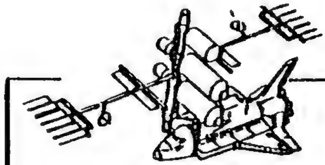
IBM SPACE SYSTEMS ENGINEERING



RATIONALE FOR IN-SPACE TECHNOLOGY EXPERIMENTS (CONTINUED)

- SOME OPERATIONAL INTERACTIONS - INVOLVING HUMANS CANNOT BE ACCURATELY SIMULATED
  - TELEOPERATIONS W/ROBOTS
- SPACE TESTING:
  - SHOULD VERIFY TECHNIQUES, SYSTEM APPROACHES WHICH CANNOT BE TESTED ON THE GROUND
  - SHOULD NOT BE USED AS BASIS FOR DEVELOPMENT OF NEW CONCEPT, OR PRIMARY TESTING APPROACH

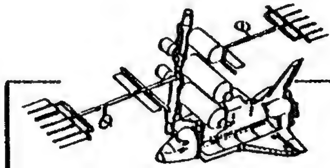
IBM SPACE SYSTEMS ENGINEERING



TRENDS IN SPACE DATA SYSTEMS

- SYSTEM ARCHITECTURES
  - MOVING TOWARD DISTRIBUTED APPROACHES
  - MERGING WITH GROUND-BASED SYSTEMS - GENERAL PURPOSE H/W
  - INCREASING USE OF STANDARDS FOR LCC REDUCTION
  - DIFFERING MILITARY/CIVILIAN APPROACHES
- NETWORKS
  - EMERGING NEED FOR HIGH SPEED (>50 MB/s)
  - CONTINUING NEED FOR SIMPLE INSTRUMENTATION BUSES, LOCAL I/O
  - EMERGING NEED FOR 10 MB/s LAN
  - FIBER OPTICS REPLACING CABLE/WIRE BUSES
- PROCESSORS
  - HIGH SPEED, SINGLE BOARD → SINGLE CHIP PROCESSORS (32 BITS)
  - LOOSELY-COUPLED ARRAYS OF PROCESSORS
  - TIGHTLY COUPLED SYSTEMS (MILITARY/SENSOR SYSTEMS)
  - ON-BOARD HIGH-SPEED VECTOR PROCESSING
  - SILICON MEMORY WITH ECC & SCRUB
  - USE OF COMMERCIAL/MILITARY SYSTEMS IN SPACE
  - USE OF COTS S/W, GENERAL PURPOSE OS
- MASS STORAGE
  - MOVING TOWARD WINCHESTER-DISK MASS STORAGE
  - OPTICAL MEMORY
  - INTEGRATED DATA BASE APPROACHES

IBM SPACE SYSTEMS ENGINEERING

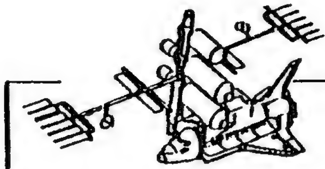


RADIATION EFFECTS ON DIGITAL ELECTRONICS

BACKGROUND

- FAILURE MODES
  - SINGLE-EVENT UPSET SEU
  - LATCH-UP
  - TOTAL DOSE
- VARIATIONS IN SPACE ENVIRONMENT
  - ORBITAL HEIGHT
  - ORBITAL INCLINATION
  - SOLAR CYCLES
  - RANDOM EVENTS (FLARES, ETC)
  - MAN-MADE EVENTS (NUCLEAR EFFECTS)
  - SHIELDING
  - PARTICLE FLUX CHARACTERISTICS
- GROUND TESTING LIMITATIONS
  - RADIATION SPECTRA
  - MODELING ACCURACY
  - CIRCUIT COMPLEXITY
  - EFFECTS REPORTING

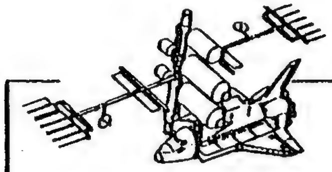
IBM SPACE SYSTEMS ENGINEERING



IN-SPACE TECHNOLOGY TESTING
NEEDS

SPACE DATA SYSTEM NEED EXAMPLES	IN-SPACE TESTING RATIONALE				
	ZERO-G ENVIRONMENT	SINGLE-EVENT EFFECTS	TOTAL-DOSE EFFECTS	OPERATION COMPLEXITY	CONFIDENCE
COMPONENTS					
VHSIC PROCESSES	X	X	X		X
"COMMERCIAL" PROCESSES-SILICON	X	X	X		X
"NEW COMPONENT" TECH-e.g. OPTICAL (DRIVES)	X	X	X		X
PROCESSORS					
NEW ISA SYSTEMS		X	X		X
ARRAY PROCESSORS					X
HIGH-SPEED BACKPLANES					X
FAULT-TOLERANT ARCHITECTURES					X
NETWORKS					
NEW MEDIA		X	X		X
ROTATING JOINT MISSION					X
NETWORK SYSTEMS					X
DRIVER/RECEIVER TECHNOLOGIES		X	X		X
MASS STORAGE					
ROTATING SYSTEMS	X				X
OPTICAL DRIVERS/RECEIVERS		X	X		X
MEDIA STABILITY		X	X		X
SOFTWARE					
OPERATING SYSTEMS					X
DBMS's					X
NETWORK OS					X
AI SYSTEMS					X
SYSTEMS					
TELE OPERATIONS				X	X
AUTOMATED SYSTEMS				X	X

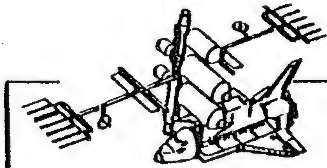
IBM SPACE SYSTEMS ENGINEERING



IN-SPACE TESTING NEEDS GENERAL

- INEXPENSIVE WAY TO TEST COMPONENTS IN SPACE FOR SEE
- INEXPENSIVE WAY TO VERIFY SYSTEMS FOR SEE, INTEGRATED EFFECTS
- LONG DURATION TEST FACILITY FOR LIFETIME TESTING - TOTAL DOSE, INTEGRATED EFFECTS
- COORDINATED GROUND TEST, MODELING PROGRAM
  - PROGRAM AND FACILITY FOR MULTIPLE EFFECTS
- ORGANIZED APPROACH TO SELECT TECHNOLOGIES WHICH REQUIRE, RECEIVE TESTING
- SIMPLE WAY TO FLY "COMMERCIAL" AND/OR "MILITARIZE" ELECTRONICS FOR QUICK EVALUATION

IBM SPACE SYSTEMS ENGINEERING



<u>SPECIFIC SUGGESTIONS</u>

- ESTABLISH COMPONENTS & SYSTEMS TESTING PROGRAM
  - COMPONENTS & SYSTEM TEST STANDARDS
  - USE STATION AS A PATHFINDER
- DEVELOP A CONCEPT FOR LONG DURATION "COMPONENTS & ELEMENTS" TEST FIXTURES
  - PERHAPS SEVERAL AT VARIOUS DURATION AND ORBITS
- EXPAND INEXPENSIVE SORTIE-LEVEL TESTING CAPABILITIES
  - TEST COMPONENTS
  - VERIFY SYSTEM ELEMENTS
  - FLY UNMODIFIED COMMERCIAL/MILITARY TECHNOLOGY

IBM SPACE SYSTEMS ENGINEERING

IN-SPACE EXPERIMENTS INFORMATION SYSTEMS

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UNIVERSITY SCIENTISTS AND ENGINEERS PERSPECTIVES ON INFORMATION SYSTEMS

- THE CATCH-22 OF SPACE INSTRUMENTATION

  - PROPOSALS ARE OFTEN AWARDED BASED UPON CONSERVATIVE 'CANNOT FAIL' DESIGNS. AT THE SAME TIME COSTS MUST BE HELD DOWN AND DELIVERY BASED UPON SUCCESS ORIENTED SCHEDULES.
    - POWER, WEIGHT, AND ENVIRONMENTAL CONSTRAINTS AFFECT SCIENTIFIC OBJECTIVES, TYPICALLY REDUCING OVERALL SCIENTIFIC RETURN.
    - H/W SHOULD BE 'OFF-THE-SHELF', USING PARTS PREQUALIFIED FOR SPACE ENVIRONMENTS. THIS FORCES USING TECHNOLOGIES AND PARTS WHICH ARE FIVE OR MORE YEARS BEHIND COMMERCIALLY AVAILABLE PARTS, AGAIN LIMITING SCIENTIFIC RETURN.
    - S/W IS LIMITED BY PROCESSOR, TECHNOLOGY (CMOS, LSTTL, HCMOS, ETC.), MEMORY SIZES, ETC., FORCING ROUTINES TO BE WRITTEN IN ASSEMBLY LANGUAGE. ALSO LIMITS CAPABILITIES TO SIMPLE CONTROL ALGORITHMS AND LOW DATA RATES.

  - YET WE LIVE IN A COMPLEX UNIVERSE, FORCING THE INSTRUMENTATION TO GROW IN COMPLEXITY AND SIZE.
    - EACH GENERATION MUST BE MORE SENSITIVE, HAVE A LARGER DYNAMIC RANGE, AND HIGHER PRECISION AND RESOLUTION THAN ITS PREDECESSOR
    - SHORT AND LONG TERM DRIFT (OVER TIME, TEMPERATURE, RADIATION, ETC) FORCE THE DEVELOPMENT OF COMPLEX, IN-FLIGHT, CALIBRATION SEQUENCES
    - DATA VOLUME IF UNINTERESTING PHENOMENA IN A 'SIT AND WAIT' MODE IS EXCESSIVE. INSTRUMENTATION NEEDS TO BE ABLE TO FIND THE HIGH QUALITY DATA THAT WILL ENHANCE SCIENTIFIC DISCOVERIES

UNIVERSITY SCIENTISTS AND ENGINEERS PERSPECTIVES ON INFORMATION SYSTEMS (CONTINUED)

- MISSION APPLICATIONS FOR FUTURE SPACE QUALIFIED INFORMATION SYSTEMS
  - ON-BOARD SENSOR-BASED 'EVENT' DETECTION AND S/C MODE RECONFIGURATION FOR 'EVENT' OBSERVATION
    - SOLAR PHYSICS (FLARES, CORONAL MASS EJECTION, CORONAL HOLES, ETC)
    - ATMOSPHERIC PHYSICS (AURORA, POLAR MESOSPHERIC CLOUDS, ETC)
    - COMETARY PHYSICS (DETECTION, COMPOSITION)
    - PLANETARY EXPLORATION (VOLCANOS , RINGS, ETC.)
    - ASTROPHYSICS (SUPERNOVAS)
  - RESOURCE MANAGEMENT
    - POWER
    - TEMPERATURE
    - DISTURBANCE TORQUES
    - DATA (COMPRESSION, BUFFERING, RATES, PACKETIZING)
  - SENSOR CALIBRATIONS
  - FAULT DETECTION AND CORRECTION
  - POINTING, ATTITUDE, AND MOTION CONTROL AND COMPENSATION

UNIVERSITY SCIENTISTS AND ENGINEERS PERSPECTIVES ON INFORMATION SYSTEMS (CONTINUED)

- DIFFICULTIES EXPERIENCED RELATING TO DEVELOPMENT AND QUALIFICATION OF NEW FLIGHT TECHNOLOGIES
  - LIMITED PERSONNEL / EXPERIENCE BASE
  - AO'S OFTEN PRECLUDE THE DEVELOPMENT OF NEW TECHNOLOGIES
  - NO PROFIT MOTIVE OR INTERNAL R & D FUNDING SOURCES
  - MOST FLIGHT PROGRAMS ARE UNWILLING TO ACCEPT THE RISKS ASSOCIATED WITH THE DEVELOPMENT OF NEW TECHNOLOGIES. SEPARATE GRANTS MUST BE OBTAINED PRIOR TO S/C FUNDING FOR DEVELOPMENT PROGRAMS

- UNIVERSITIES SUFFER FROM POOR OR CONFLICTING DATA PERTAINING TO SPACE QUALIFIED PARTS
  - EACH NASA CENTER USES DIFFERENT APPROVED PARTS AND FABRICATION TECHNIQUES
  - NEWER TECHNOLOGIES IN THE PROCESS OF QUALIFICATION ARE NOT WIDELY PUBLISHED
  - DOD SPACE QUALIFIED PARTS CANNOT BE OBTAINED

UNIVERSITY SCIENTISTS AND ENGINEERS PERSPECTIVES ON INFORMATION SYSTEMS (CONTINUED)

- LITTLE OR NO STANDARDIZATION OF S/C INTERFACES, BUS STANDARDS, ETC. THUS EVERY INSTRUMENTS DESIGN IS UNIQUE EVEN THOUGH MANY INCORPORATE SUBSYSTEM COMMON TO ALL
    - MICROPROCESSOR / BUS
    - ECC MEMORY
    - TELEMETRY INTERFACE
    - STANDARD INTERFACES (MULTICHANNEL A/D'S AND D/A'S, ETC)
    - SOFTWARE

UNIVERSITY SCIENTISTS AND ENGINEERS WILL PUSH AVAILABLE FLIGHT DESIGNS AND TECHNOLOGIES TO THEIR LIMITS. HOWEVER, THEY WILL NOT PROPOSE INSTRUMENTATION REQUIRING THE DEVELOPMENT OR QUALIFICATION OF NEWER, COMMERCIALLY AVAILABLE PARTS AND TECHNOLOGIES, UNDER S/C ANNOUNCEMENT OF OPPORTUNITIES.

TECHNOLOGY NEEDS

- INTELLIGENT (NETWORKED) INSTRUMENTATION AND S/C
  - ON-BOARD CALIBRATION SEQUENCING
    - S/C MANEUVERING
    - INSTRUMENT CONFIGURATION
    - SENSOR DATA CALIBRATION ANALYSIS
    - STORAGE OF CALIBRATION DATA
  - REAL-TIME DATA PROCESSING
    - APPLICATION OF CALIBRATION DATA
    - BACKGROUND REMOVAL
    - ANALYTICAL ANALYSIS (MIN / MAX, FFT, MODEL FITTING, ETC)
    - DATA COMPRESSION
  - DATA ANALYSIS
    - 'EVENT' DETECTION AND FEATURE RECOGNITION
  - 'EVENT' BROADCAST AND RECONFIGURATION
    - INSTRUMENT
    - S/C
    - OTHER (OTHER S/C, GROUND INSTRUMENTATION, SS INSTRUMENTATION, ETC.)
  - RESOURCE MANAGEMENT

TECHNOLOGY NEEDS (CONTINUED)

- SPACE-QUALIFIED PARTS / SYSTEMS
  - STANDARDIZED BUS PROTOCOL(S)
    - 'OFF-THE-SHELF' SPACE-QUALIFIED COMPONENTS
      - 8, 16, & 32 BIT FAULT TOLERANT MICROPROCESSOR CARDS
      - ECC MEMORY (PROM, EPROM, SRAM, AND DRAM)
      - TELEMETRY INTERFACE CARDS (SHOULD COMPLY WITH COMMERCIALLY AVAILABLE STANDARDS LIKE RS-232, IEE-488, ETHERNET, ETC.)
      - CONTROL I/F CARDS (DIGITAL I/O, A/D, D/A, ETC.)
      - **LITERALLY SPACE QUALIFIED PC'S, MAC II'S, MICROVAX'S, ETC. WITH PLUG IN PERIPHERAL CARDS**
  - SOFTWARE UTILITIES SUPPORTING HARDWARE SYSTEMS
    - REAL-TIME MULTITASKING KERNEL
    - PACKET GENERATION UTILITIES
    - DATA COMPRESSION UTILITIES
    - COMMAND ERROR CHECKING AND PARSING UTILITIES
    - GROUND BASED COMPLEMENTS TO THE ABOVE UTILITIES
    - RESOURCE MANAGEMENT UTILITIES

TECHNOLOGY NEEDS (CONTINUED)

- NATIONAL NASA APPROVED PARTS AND SOFTWARE DATABASE
  - CONTINUOUSLY UPDATED
    - DISCRETE PARTS AND MATERIALS
    - COMPONENT LEVEL CARDS / BOARDS
      - SPECIFICATIONS
      - QUALIFICATION LEVEL (MIL-STD-883, MIL-M-38510, ETC.)
      - RADIATION HARDNESS
      - VENDOR
      - PRICE
    - SOFTWARE UTILITIES
    - CURRENT R & D EFFORTS
    - USER FEEDBACK / WISH LISTS

SENSORS AND INFORMATION SYSTEMS CRITICAL TECHNOLOGY REQUIREMENTS

MARTIN M. SOKOLOSKI
NASA HEADQUARTERS
and
JOHN DALTON
GODDARD SPACE FLIGHT CENTER

SENSORS IMPORTANCE

MISSION TO PLANET EARTH

EOS

- Laser Active Sensing of Winds
- Laser Active Sensing of Trace Species
  - Ozone, Acid Rain, H_2O, CO_2, Others
- Laser Altimetry
  - Plate Tectonic Movements

GEOPLAT

- Fixed Focus with Large Format Arrays
- Multi-Spectral Imagers
- Spatial Imagers

SENSORS IN-SPACE TESTING REQUIRED

- IN-SPACE POINTING, CONTROL & STABILIZATION TEST BED FOR DETECTORS & LASERS REMOTE SENSING SYSTEMS

- IN-SPACE TESTING, DEMONSTRATION, AND VERIFICATION OF PROTOTYPE COOLERS & COOLER SYSTEMS
  - Mechanical Refrigerators
  - Magnetic Refrigerators
  - He3/He4 Dilution Refrigerators

SENSORS TECHNOLOGY NEEDS

- o PRECISION POINTING, CONTROL & STABILIZATION FOR PASSIVE AND ACTIVE (DIAL/LIDAR) REMOTE SENSING
  - o Passive Sensing (Detector Arrays)
    - "Earth Looking"
    - "Out Looking"
  - o Active Sensing
    - Differential Absorption LIDAR
    - Coherent Doppler LIDAR [Laser Atmospheric Wind Sounder]
- o SPACE - QUALIFIABLE COOLERS & COOLER SYSTEMS OPERATING IN 0-G ENVIRONMENT ~ 3-5 YEARS LIFETIME
  - o Cooling Sensor Arrays to Tens of Kelvin
  - o Cooling Sensor Arrays to Millikelvin $<T<$ 10ok

COMMUNICATIONS IMPORTANCE

- MISSION TO PLANET EARTH
  - Optical (>500 Mbps) GEOPLAT/GEOPLAT Links
  - GEOPLAT/EOS Links
  - Coherent Links [Two or More Platforms Employed as a Single Observational Instrument]
  - Optical Link Direct to Ground
- MARS EXPLORATION
  - Mars Rover (Eliminate Large Antenna)
  - Manned Missions
- LUNAR BASE
  - LaGrange Point / Earth -GEO / Far Side Optical Link
- OTHER MISSIONS
  - Enables Star Probe (Communication in and Thru Sun's Plasma)
  - TAU (Thousand Astronomical Unit)
  - Planetary - High Data Rate

COMMUNICATIONS TECHNOLOGY NEEDS

- EXPERIMENTAL TEST DATA ON OPTO-THERMO-STRUCTURAL MECHANICAL INTERACTIONS OF SPACE-BASED "OPTICAL BENCH" FOR OPTICAL COMMUNICATIONS
  - Laser Power & Cooling
  - Acquisition (Closed & Open Loop)
  - Pointing and Tracking
  - Communications Links
  - Very Large Baselines (>40,000 Km)

COMMUNICATIONS IN-SPACE TESTING REQUIRED

- Obtain Experimental Test Data to Obtain and Validate Complex Analytical Models to Enable Overall Laser Communications Systems Optimization

- The In-Space Environment:
  - Platform Vibration
  - Thermal Distortion
  - Radiation
  - Natural Background Sources
  - S/C Glow
  - Long Baselines

INFORMATION SYSTEMS TECHNOLOGY NEEDS

- **Intelligent Information Systems to Support Automated Operations, On-Board Processing, & Robotics**
  - **Special Purpose Processors: Image, Symbolic, Neural Network**
  - **High Performance General Purpose Processors**
  - **High Volume Storage**

IMPORTANCE

- MISSION TO EARTH:
  - **On-Board Feature Extraction & Processing Required to Reduce Large Volume of Global Monitoring Data and Enable Manageable Communications and Ground Processing Costs**
- MICROGRAVITY:
  - **On-Board Selection of Features of Interest From High Rate/Volume Image Sequences. Required to Meet TDRS Communication Limit**
- PLANETARY ROVERS:
  - **On-Board Science Analysis & Autonomous Vehicle Operation**

INFORMATION SYSTEMS TECHNOLOGY NEEDS (CONT.)

IN-SPACE TESTING REQUIRED

- o System-Level Validation:
  - Adaptive Response to Real-Time Observations
  - Performance and Reliability in Space Radiation Environment
- o Space Environment Testing
  - Space-Borne VHSIC Multiprocessor System
  - CSTI High Rate Data Systems

INFORMATION SYSTEMS IN-SPACE TECHNOLOGY NEEDS

- o Space Qualified Components with Performance Comparable to Ground System Capability
- o Confidence Testing of Commercial-Grade Components to Provide Low-Cost, Low-Risk Applications
- o Zero-G Testing of Storage Systems

IMPORTANCE:

- o Reduce Cost of Space Experiments
- o Modular, Standard Processing Elements for Multi-Mission Applications
- o Mission Enabling for Some Applications (Eg. On-Board Instrument Calibration, Automation of Operations)

INFORMATION SYSTEMS IN-SPACE TECHNOLOGY NEEDS (CONT.)

IN-SPACE TESTING REQUIRED:

- o Laboratory for On-Going Testing of New Components
  - Shuttle/SSF Low Inclination Orbit
  - Polar & Geo Radiation Environment
- o Build on CRRES Experience
- o Improve Model of Radiation Environmental Effects
- o Incorporate as Last Step of Ground Modeling & Testing Process

SENSORS & INFORMATION SYSTEMS IN-SPACE TECHNOLOGY NEEDS

SENSORS

- Precision Pointing, Control, and Stabilization
- Coolers

COMMUNICATIONS

- High Rate Optical Communications
- Closed and Open Loop Acquisition
- Pointing and Tracking

INFORMATION SYSTEMS

- Intelligent Systems For In-Space Observations, Automated Control, and Robotics
- Effective Space Application of Processor and Storage Technology Advances

7. IN-SPACE SYSTEMS

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IN-SPACE SYSTEMS
BACKGROUND AND OBJECTIVES

JON B. HAUSSLER
MARSHALL SPACE FLIGHT CENTER

THEME SESSION OBJECTIVES

- PURPOSE
  - IDENTIFY & PRIORITIZE IN-SPACE TECHNOLOGIES FOR EACH THEME WHICH:
    - ARE CRITICAL FOR FUTURE NATIONAL SPACE PROGRAMS
    - REQUIRE DEVELOPMENT & IN-SPACE VALIDATION
  - OBTAIN AEROSPACE COMMUNITY COMMENTS & SUGGESTIONS ON OAST IN-STEP PLANS
- PRODUCT
  - AEROSPACE COMMUNITY RECOMMENDED PRIORITY LISTING OF CRITICAL SPACE TECHNOLOGY NEEDS & ASSOCIATED SPACE FLIGHT EXPERIMENTS

IN-SPACE SYSTEMS

THEME ELEMENTS
(*SUBTHEMES*)

MATERIAL PROCESSING

MAINTENANCE, REPAIR AND FIRE SAFETY

PAYLOAD OPERATIONS

1985 WORKSHOP THEME

IN-SPACE OPERATIONS

- ADVANCED LIFE SUPPORT SYSTEM
- BIOMEDICAL RESEARCH
- TETHERS
- MAINTENANCE AND REPAIR
- ORBITAL TRANSFER VEHICLE
- SYSTEM TESTING
- PROPULSION
- MATERIAL PROCESSING

THEME SESSION AGENDA

• *THEME ELEMENT SESSIONS*

- CRITICAL SPACE TECHNOLOGY NEEDS FOR THEME ELEMENT.

  FROM PERSPECTIVE OF:

  - INDUSTRY, UNIVERSITIES & GOVERNMENT

    (BRIEF PRESENTATIONS OF MAJOR TECHNICAL PROBLEMS/CONCERNS/NEEDS IN THIS THEME ELEMENT AREA FROM THE PERSPECTIVE OF THE SPEAKER'S ORGANIZATION)

- OPEN DISCUSSION WITH THE AUDIENCE & THEME ELEMENT SPEAKERS/THEME LEADER
  - QUESTION & ANSWER WITH SPEAKERS
  - IDENTIFICATION OF ADDITIONAL TECHNOLOGIES FROM AUDIENCE
- AUDIENCE PRIORITIZATION OF CRITICAL TECHNOLOGIES

  (INCLUDING THOSE TECHNOLOGIES DISCUSSED BY THE AUDIENCE)

  (NOTE: AUDIENCE SHOULD USE PRIORITIZATION CRITERIA PRESENTED ON VIEWGRAPH)

• *COMBINATION & PRIORITIZATION OF THEME TECHNOLOGIES*

- DISCUSSION BETWEEN AUDIENCE AND ALL THEME ELEMENT SPEAKERS
- RESOLUTION OF CRITICAL TECHNOLOGIES ACROSS THEME

IN-SPACE SYSTEMS

MATERIAL PROCESSING SPEAKERS

- DR. ROBERT J. NAUMANN, MSFC
- DR. DAVID W. SAMMONS, UNIVERSITY OF ARIZONA
- DR. JOHN T. VIOLA, ROCKWELL INTERNATIONAL

IN-SPACE SYSTEMS

MAINTENANCE AND REPAIR SPEAKERS

- MR. ED FALKENHAYN, GSFC

- MR. BOB DELLACAMERA, MCDONNELL DOUGLAS

FIRE SAFETY SPEAKER

- MR. WALLACE W. YOUNGBLOOD, WYLE LABORATORIES

IN-SPACE SYSTEMS

PAYLOAD OPERATIONS SPEAKERS

- DR. JEFFREY A. HOFFMAN, JSC
- PROF. GEORGE MORGENTHALER, UNIVERSITY OF COLORADO
- MR. LEE LUNSFORD, LOCKHEED

PRIORITIZATION CRITERIA*

1. CRITICAL ENABLING TECHNOLOGIES

- TECHNOLOGIES WHICH ARE CRITICAL FOR FUTURE U.S. SPACE MISSIONS

2. COST REDUCTION TECHNOLOGIES

-TECHNOLOGIES WHICH CAN DECREASE COSTS OR COMPLEXITY (E.G., DEVELOPMENT, LIFE-CYCLE, OPERATIONS)

3. BROAD APPLICATION TECHNOLOGIES

- TECHNOLOGIES WHICH CAN IMPROVE OR ENHANCE A VARIETY OF SPACE MISSIONS

4. REQUIRE IN-SPACE VALIDATION

-TECHNOLOGIES WHICH REQUIRE THE SPACE ENVIRONMENT OR MICRO-GRAVITY FOR VALIDATION OR EXPERIMENTATION

* CRITERIA ARE LISTED IN ORDER OF IMPORTANCE (1. = HIGHEST)

7.1 MATERIALS PROCESSING

OFFICE OF SPACE SCIENCE AND APPLICATIONS

MICROGRAVITY SCIENCE AND APPLICATIONS DIVISION

NASA HEADQUARTERS

IN SPACE TECHNOLOGY EXPERIMENTS PROGRAM

1988 WORKSHOP

MATERIALS PROCESSING

DECEMBER 7, 1988

LARRY SPENCER

WHY MICROGRAVITY?

- **ELIMINATE BUOYANCY-DRIVEN CONVECTION**

  ESTABLISH DIFFUSION-CONTROLLED CONDITIONS
  VASTLY SIMPLIFIES TRANSPORT ANALYSIS
  SUPPRESSES THERMAL AND COMPOSITION FLUCTUATIONS
  ELIMINATES UNWANTED MIXING
  UNMASKS OTHER, MORE SUBTLE FLOWS

- **ELIMINATE SEDIMENTATION**

  MAINTAIN HETEROGENEOUS MIXTURES OR SUSPENSIONS
  PREVENT UNWANTED PHASE SEPARATION
  INVESTIGATE SECOND-ORDER FORCES ON PARTICLES OR DROPLETS
  OBJECTS CAN BE FREE-FLOATED

- **ELIMINATE HYDROSTATIC PRESSURE**

  LIQUID CAN BE CONSTRAINED BY THEIR SURFACE TENSION
  DEPLOY LIQUID BRIDGES TO RAYLEIGH LIMIT
  EXTEND FLOAT ZONE PROCESS TO LOW SURFACE TENSION MATERIALS
  ELIMINATE PRESSURE VARIATIONS IN CRITICAL POINT EXPERIMENTS

BONUSES

ULTRAHIGH VACUUM — $\sim 10^{-14}$ TORR BEHIND WAKE-SHIELD
HIGH PUMPING SPEED — VIRTUALLY INFINITE SINK
HIGH HEAT REJECTION — $\sim$4K RADIATION BACKGROUND
FLUX OF ATOMIC OXYGEN — COLLIMATED BEAM OF 5 ev 0 ATOMS
UNFILTERED SUNLIGHT — SOURCE OF V.U.V. ESPECIALLY 121.6 n.m.

GOALS

- USE THE MICROGRAVITY ENVIRONMENT AS A LABORATORY TO:

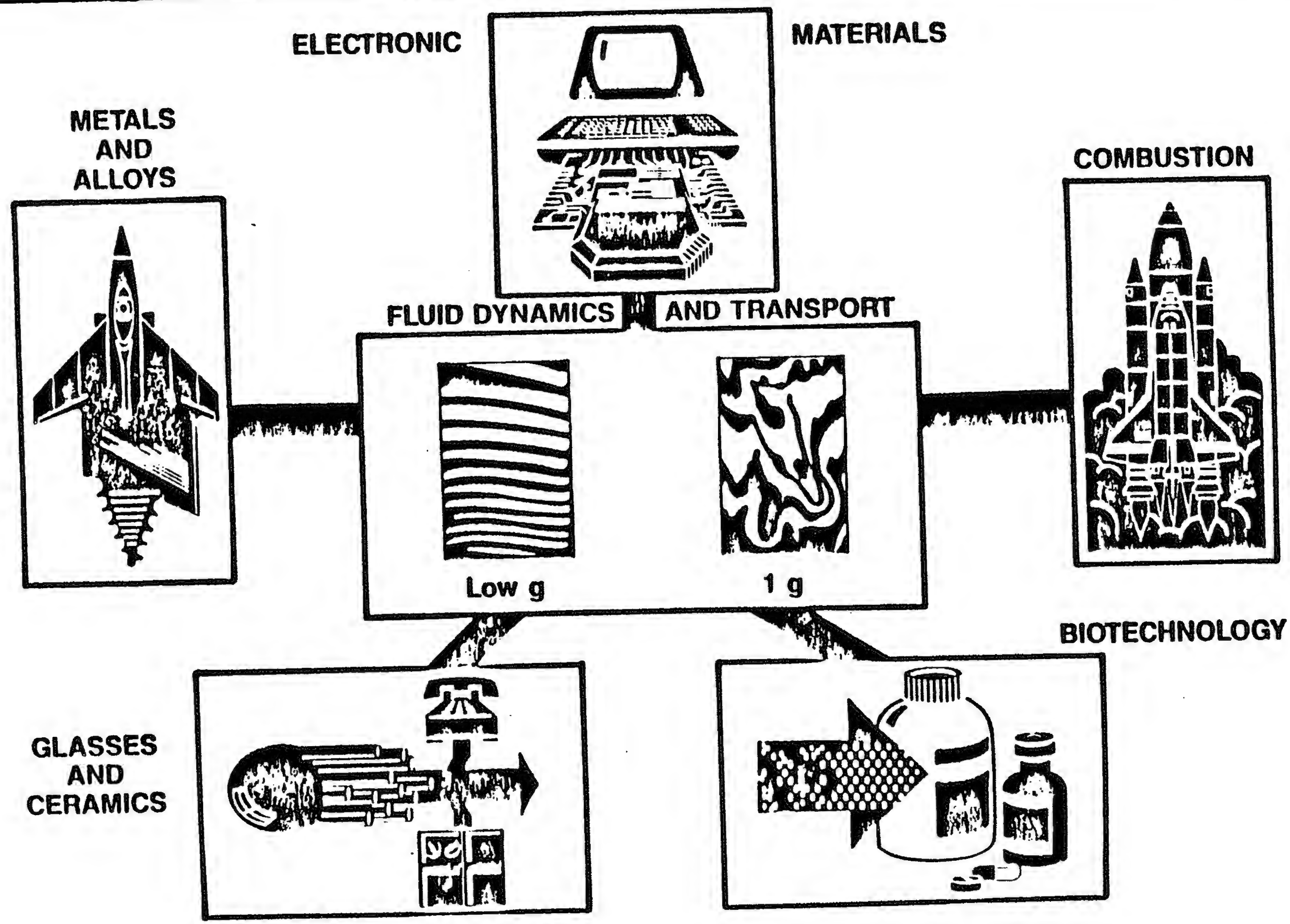
  1) OBTAIN UNDERSTANDING OF BASIC PHYSICAL PHENOMENA AND PROCESSES

  2) QUANTIFY LIMITATIONS/EFFECTS IMPOSED BY GRAVITY ON THESE PHENOMENA AND PROCESSES

  3) APPLY THIS BASIC KNOWLEDGE TO BOTH EARTH BASED AND SPACE BASED PROCESSES OR PRODUCTS

- DISSEMINATE THE RESEARCH DATA BASE TO THE U.S. PRIVATE SECTOR TO ENHANCE U.S. COMPETITIVENESS IN THE WORLD MARKET

MICROGRAVITY SCIENCE AND APPLICATIONS DIVISION



MICROGRAVITY SCIENCE AND APPLICATIONS DISCIPLINES

FLUID DYNAMICS AND TRANSPORT PHENOMENA
- CRITICAL POINT PHENOMENA
- SURFACE BEHAVIOR
- CHEMICAL REACTION
- RELATIVITY
- TRANSPORT PHENOMENA
- SOLIDIFICATION MODELS

GLASSES AND CERAMICS
- NEW GLASS COMPOSITIONS
- FINING
- SPHERICAL SHELLS
- NUCLEATION/CRYSTALLIZATION

ELECTRONIC MATERIALS
- VAPOR GROWTH
- MELT GROWTH
- SOLUTION GROWTH
- FLOAT ZONE

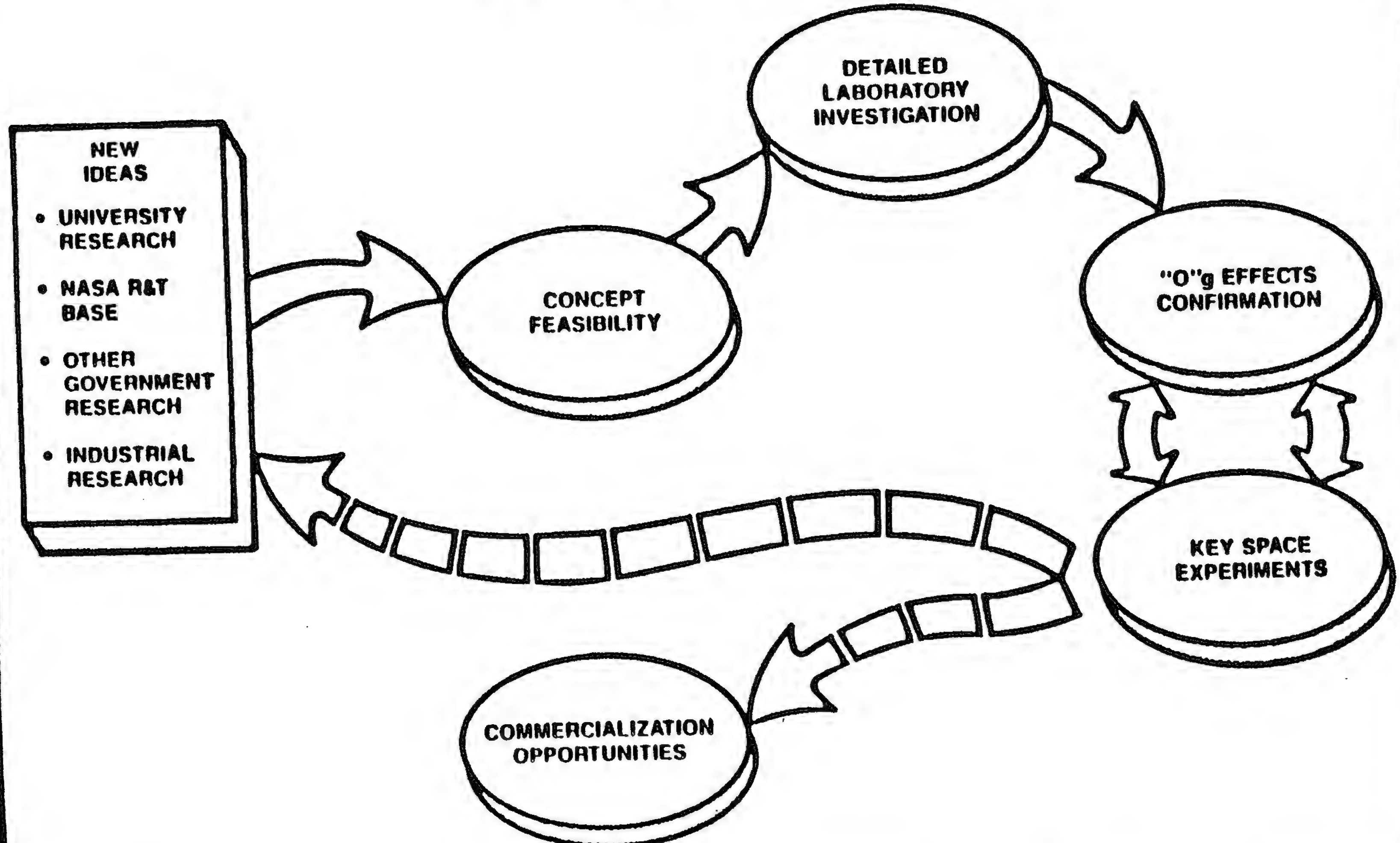
METALS AND ALLOYS
- MONOTECTICS
- EUTECTICS
- UNDERCOOLING
- SOLIDIFICATION FUNDAMENTALS
- THERMOPHYSICAL PROPERTIES

BIOTECHNOLOGY
- NEW TECHNIQUE DEVELOPMENT
- EVALUATION OF CFES
- PROTEIN CRYSTAL GROWTH
- BIOREACTOR

COMBUSTION SCIENCE
- SOLID SURFACE
- POOL BURNING
- PARTICLE CLOUD
- DROPLET BURNING

NASA OFFICE OF SPACE SCIENCE AND APPLICATIONS
MICROGRAVITY SCIENCE AND APPLICATIONS DIVISION

THE APPROACH



MICROGRAVITY SCIENCE AND APPLICATIONS TECHNOLOGY DEVELOPMENT

- VIBRATION ISOLATION SYSTEMS (10^{-8}g, 10^{-3}Hz)
- REACTIONLESS ROBOTICS
- ADVANCED HIGH-TEMPERATURE FURNACES
- HIGH-TEMPERATURE MATERIALS FOR FURNACES (3000°C)
- HIGH-FRAME RATE/HIGH-RESOLUTION VIDEO (100 microns, 1000 FPS)
- CRYSTAL GROWTH NUCLEATION DETECTION (10Å)
- NON-CONTACT TEMPERATURE MEASUREMENT CAPABILITY (5°K TO 2500°K)
- ELECTRONIC CRYSTAL GROWTH MEASUREMENT TECHNOLOGY
- FLUID AND COMBUSTION DIAGNOSTICS
- ACCELERATION MEASUREMENT (10^{-8}g)

IN-SPACE TECHNOLOGHY VALIDATION NEEDS

- CHARACTERIZATION, MEASUREMENT, AND CONTROL OF THE MICROGRAVITY ENVIRONMENT
- ULTRAHIGH VALUUM TECHNOLOGY
- MEASUREMENT AND CONTROL OF FLUIDS
- REACTIONLESS ROBOTICS
- IN-SPACE SAMPLE PREPARATION AND ANALYSIS
- HANDLING OF MATERIALS AND WASTE PRODUCTS
- COMBUSTION DIAGNOSTIC TECHNOLOGY

FLOATING-ZONE CRYSTAL GROWTH IN SPACE

JOHN T. VIOLA

ROCKWELL INTERNATIONAL SCIENCE CENTER

INTRODUCTION / BACKGROUND

- O ELECTRONIC COMPONENTS AND SUBSYSTEMS FOR DEFENSE AND COMMERCIAL APPLICATIONS IN DEVELOPMENT
  - GaAs SIGNAL PROCESSORS, INFRARED FOCAL PLANE ARRAYS, NON-LINEAR OPTICS AND PHOTONICS
- O HIGH QUALITY, DEFECT-FREE MATERIAL IS NEEDED FOR THESE APPLICATIONS
- O CURRENT TECHNOLOGY LIMITS SINGLE CRYSTAL SIZE AND IMPOSES UNWANTED DEFECT CONCENTRATIONS (TWINS, DISLOCATIONS, PRECIPITATES, GRAIN BOUNDARIES)

INTRODUCTION / BACKGROUND - CONTINUED

- O FLOAT ZONE CRYSTAL GROWTH IN MICROGRAVITY CAN YIELD LARGER CRYSTALS WITH LOWER DEFECT CONCENTRATIONS.
  - O REDUCED CONTAMINANT CONCENTRATION AND SPURIOUS NUCLEATION BY ELIMINATION OF INTRACTION WITH AN AMPOULE
  - O LARGER DIAMETER ZONE IS POSSIBLE SINCE SURFACE TENSION NEED NOT SUPPORT THE WEIGHT OF THE MELTED ZONE
  - O ELIMINATION OF PLASTIC DEFORMATION FROM CRYSTAL'S OWN WEIGHT.
- O FLOAT ZONE EXPERIMENTS IN SPACE ARE NEEDED TO DEMONSTRATE FEASIBILITY

TECHNOLOGY NEEDS

0 EXPERIMENTAL FACILITY NEEDED TO PERFORM CONTROLLED CRYSTAL GROWTH OF HIGH MELTING ELECTRONIC MATERIALS WITH HIGH CONSTITUENT VAPOR PRESSURES.

REQUIREMENT	PURPOSE
SAMPLE SUPPORT AND CHANGEOUT	CONTACTLESS PROCESSING; MULTIPLE EXPERIMENTS
FURNACE TEMPERATURES UP TO 1500C	ELECTRONIC MATERIALS OF INTEREST
HOT WALL FURNACE	ELIMINATE VAPOR LOSS BY CONDENSATION
VARIABLE SPEED ZONE HEATER	ESTABLISH AND MOVE MOLTEN ZONE
POWER BUDGET MANAGEMENT	ESTABLISH AND MAINTAIN PROPER TEMPERATURE PROFILE
MOLTEN ZONE DIMENSIONAL SENSING (LENGTH, SOLID-LIQUID INTERFACES FLUID FLOWS)	OPTIMIZE CRYSTAL GROWTH CONDITIONS

TECHNOLOGY NEEDS

REQUIREMENT	PURPOSE
FURNACE AND GROWTH SYSTEM TEMPERATURE SENSING	OPTIMIZE CRYSTAL GROWTH CONDITIONS
CONTROLLABLE POWER AND POSITIONAL SETTINGS	ESTALISH AND MAINTAIN PROPER TEMPERATURE PROFILE
EVENTUAL EXPERT SYSTEM CONTROL	AUTONOMOUS OPERATION
PROVE FOR IN SITU OBSERVATION OF GROWING CRYSTAL QUALITY (ULTRASOUND?)	EXPERT SYSTEM CONROL OF GROWTH PROCESS
ROBOTIC MANIPULATION	AUTONOMOUS OPERATION/TELESCIENCE

IN-SPACE EXPERIMENTATION NEEDS / VOIDS

0 FLOATING-ZONE CRYSTAL GROWTH OF HIGH-MELTING SEMICONDUCTOR COMPOUNDS TO DEMONSTRATE LARGE SIZE, HIGH PURITY, LOW DEFECT, SINGLE CRYSTAL MATERIAL.

0 "CONTAINERLESS" PROCESSING TO DEMONSTRATE ADVANTAGES OF CONTACTLESS CRYSTAL GROWTH.

0 SENSING AND IMAGING SYSTEM FOR FLOATING-ZONE CRYSTAL GROWTH TO DEMONSTRATE CONTROL OF MOLTEN ZONE SIZE, LENGTH, SHAPE AND RELATIVE MOTION AND FLOW.

0 EXPERIMENTS TO INVESTIGATE FLUID DYNAMIC PHENOMENA, SUCH AS THERMOCAPILLARY FLOW, THAT ARE OF CRITICAL IMPORTANCE IN EARTH-BASED PROCESSES, BUT CANNOT BE STUDIED ON EARTH BECAUSE OF GRAVITATIONAL EFFECTS; RESULTS CAN BE APPLIED IN BOTH EARTH AND SPACE-BASED PROCESSES.

MATERIALS PROCESSING --

CELLS AND CELLULAR PRODUCTS

DAVID W. SAMMONS

UNIVERSITY OF ARIZONA

INTRODUCTION / BACKGROUND

EXPERIMENTS WITH CELLS UNDER MICROGRAVITY ARE IMPORTANT TO:

- BASIC SCIENCE
- COMMERCIALIZATION OF BIOTECHNOLOGY
- SPACE MEDICINE AND HUMAN ADAPTATION
- TRANSFER OF SPACE TECHNOLOGY TO TERRESTRIAL APPLICATIONS

TECHNOLOGY NEEDS

- HARDWARE FOR CELL MAINTENANCE & GROWTH
- HARDWARE FOR PROLONGED CELL STORAGE AND ACTIVATION
- VISION SYSTEMS FOR COUNTING, MEASURING AND EVALUATING CELLS
- AUTOMATED FLUID TRANSFER SYSTEMS THAT MAINTAIN STERILE ENVIRONMENTS
- SEPARATION SYSTEMS UTILIZING CELLULAR & BIOPHYSICAL CHARACTERISTICS OF TARGET CELLS

TECHNOLOGY NEEDS

- ANALYSIS & QUALITY CONTROL INSTRUMENTATION
- TELECOMMUNICATION & EXPERT SYSTEMS TO MONITOR & ADJUST IN-SPACE EXPERIMENTATION
- MAINTENANCE & CONTINUED GROWTH INSTRUMENTATION FOR NEW IN-SPACE GENERATED PRODUCTS
- RECOVERY AND ANALYSIS SYSTEMS OF IN-SPACE GENERATED CELL PRODUCTS

IN-SPACE EXPERIMENTATION NEEDS/VOIDS

SAMPLE PREPARATION AND PROCESSING

- O SAMPLE INJECTION
- O LIQUID MIXING DEVICES

MAINTENANCE AND/OR CULTURE

- O GAS & TEMPERATURE CONTROLLED INCUBATORS

SEPARATION OF CELLS (POPULATION & SINGLE)

- O ELECTROKINETIC
- O CELL SORTING
- O AFFINITY

IN-SPACE EXPERIMENTATION NEEDS/VOIDS

TRANSFER OF FLUIDS & CELLS INTO REACTOR AND OUT OF REACTOR

- O VALVING
- O PUMPING OF FLUIDS

REACTION CHAMBERS

- O ELECTROFUSION/ELECTROPERMEATION
- O CELL ACTIVATION
- O HOLDING TANKS FOR SECRETION OF PRODUCTS

IN-LINE SEPARATION OF CELLS AND PRODUCTS

- O ELECTROKINETIC
- O CELL SORTING
- O AFFINITY

IN-SPACE EXPERIMENTATION NEEDS/VOIDS

RECYCLE UNREACTED CELLS TO MAINTENANCE AND/OR CULTURE

- O VALVING
- O PUMPING OF FLUIDS

SPECIALIZED CLONING AND GROWTH CHAMBERS

- O AUTOMATIC DILUTORS
- O GELS AND SPECIAL GROWTH CHAMBERS

ANALYSIS OF CLONES & ESTIMATION OF YIELDS

- O COLORIMETRIC, FLUOREMETRIC & RADIOACTIVE

RECOVERY OF CELL PRODUCT FOR RETURN OR FURTHER PROCESSING

- O INCUBATORS
- O AFFINITY RESIN MATERIALS OF HIGH CAPACITY

7.2 MAINTENANCE, REPAIR, AND FIRE SAFETY

MAINTENANCE, SERVICING & REPAIR IN SPACE

Ed Falkenhayn

SATELLITE SERVICING PROJECT

GODDARD SPACE FLIGHT CENTER

GREENBELT, MARYLAND

INTRODUCTION/BACKGROUND

CURRENT/PLANNED MAINTENANCE & REPAIR CAPABILITY

- PAYLOADS PLANNING ON STS, SPACE STATION OR OMV DOCKING WILL DOCK TO FSS THREE LATCH BERTHING RING

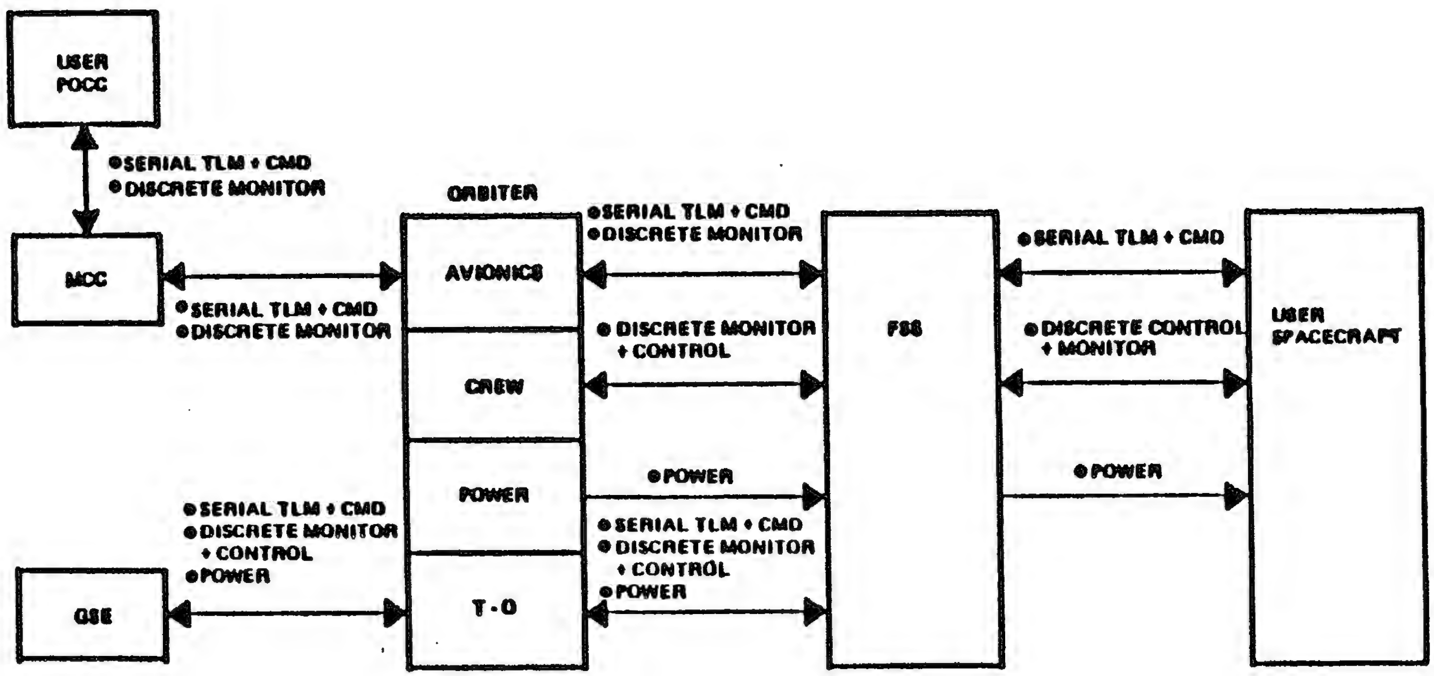
- FSS BERTHING RING PROVIDES ELECTRICAL UMBILICAL SERVICES:
  - POWER
  - DATA
  - COMMAND

- FSS BERTHING RING PROVIDES MECHANICAL POSITIONING
  - PIVOTS 0 TO 90^{o}
  - ROTATION $\pm 175^{o}$

OPERATIONS/FUNCTIONS

- POSITIONING FOR INSPECTION AND EASE OF ACCESS
- TOTAL OR SELECTIVE POWER-OFF TO PERMIT REPAIR AND/OR MODULE EXCHANGES
- INDEPENDENT HEATER POWER TO MAINTAIN THERMAL LIMITS ON COMPONENTS/INSTRUMENTS/SYSTEMS
- COMMAND & TELEMETRY LINKS PERMIT SPACECRAFT/PAYLOAD CHECKOUT
  - FROM ORBITER AFT FLIGHT DECK
  - FROM USER'S POCC VIA ORBITER AVIONICS
- AFTER SMM REPAIR IN 1984, DURING NIGHT, BETWEEN REPAIR DAY & RELAUNCH DAY, FULL SPACECRAFT FUNCTIONAL CHECK WAS PERFORMED

FSS ELECTRICAL AND AVIONICS SERVICES



DIAGNOSTIC SYSTEMS

THE ON-BOARD COMPUTER - NSSC-1

- ON-BOARD MANAGEMENT, AND UPDATING OF SPACECRAFT PERFORMANCE STATISTICS & TREND DATA
- AUTOMATIC RESPONSES TO PREDEFINED SPACECRAFT ANOMALIES/HARDWARE FAILURES - SAFE HOLD
- ALLOWS IN-FLIGHT TELEMETRY FORMAT MODIFICATIONS FOR DIAGNOSTICS AND RECONFIGURATION FOR OPTIMUM SCIENCE RETURN AS HARDWARE/INSTRUMENTS AGE AND DEGRADE

REMOTE SERVICING - THE NEXT STEP

- MANY SPACECRAFT OPERATE BEYOND STS/OMV AND SPACE STATION/OMV ALTITUDE AND INCLINATION

- REMOTE SERVICING WILL USE ELV LAUNCHED SERVICING OPERATIONS; ENGINEERING STUDIES NEED TO ADDRESS:

  - INVESTMENT IN ELV LAUNCHED, EXPENDABLE SERVICER CAPABILITY
  - PROGRAMMATICS/LOGISTICS/ECONOMICS OF A SPACE BASED SERVICING FACILITY
  - SERVICER/SPACECRAFT INTERDEPENDENCY; SHUT DOWN/TRANSFER OF SPACECRAFT FUNCTIONS
  - MANIPULATOR SYSTEM REQUIREMENTS/CAPABILITIES
  - TELEOPERATOR VS SUPERVISED AUTONOMOUS VS AUTONOMOUS OPERATIONS

SPACECRAFT FIRE SAFETY FOR ADVANCED SPACECRAFT

WALLACE W. YOUNGBLOOD
WYLE LABORATORIES
HUNTSVILLE, ALABAMA

BACKGROUND

- EARLY SPACECRAFT (MERCURY THROUGH APOLLO) UTILIZED A PURE OXYGEN ATMOSPHERE AT 5 PSIA
- SKYLAB UTILIZED AN ATMOSPHERE OF 65% OXYGEN, 35% NITROGEN AT 5.2 PSIA
- STS SHUTTLE & SPACELAB ADOPTED A SEA LEVEL AIR ATMOSPHERE
- FIRE DETECTORS (UV SENSORS) FIRST USED ON SKYLAB
- A PORTABLE FOAM FIRE EXTINGUISHER WAS PROVIDED ON THE APOLLO CSM
- FIXED AND PORTABLE HALON 1301 EXTINGUISHANT SYSTEMS ADOPTED FOR STS SHUTTLE
- DESIGN IS NOT FIRM FOR SPACE STATION
- ALL ASPECTS OF SPACECRAFT FIRE SAFETY MUST BE REVISITED:
  - MATERIAL SELECTION/CONFIGURATIONS
  - MATERIAL FLAMMABILITY/FLAME SPREAD
  - FIRE DETECTION/SUPPRESSION
  - HUMAN EFFECTS
  - ATMOSPHERES (NOMINAL/OFF-NOMINAL)

TECHNOLOGY NEEDS

DATA BASE NEEDS FOR LOW GRAVITY IGNITION/FLAME SPREAD:

- CRITICAL HEAT FLUX REQUIRED FOR IGNITION
- EFFECT OF RADIATION ENVIRONMENT
- FLAME SPREAD RATE AND EXTINCTION LIMITS
- FLAME CHARACTERISTICS: FLAME SHAPE, TEMPERATURE AND COLOR; RADIANT ENERGY; SOOT GENERATION

UPGRADED MATERIAL FLAMMABILITY STANDARDS:

- EXPANDED DATA BASE NEEDED FOR MATERIAL IGNITION AND FLAME SPREAD IN LOW GRAVITY
- STANDARDS NEEDED FOR CONFIGURATION MODELING
- DEVELOPMENT OF CORRELATIONS FOR LOW GRAVITY FLAMMABILITY
- UNIFORM FLAMMABILITY TESTS FOR NASA, ESA, NASD...

TECHNOLOGY NEEDS

FIRE DETECTION DEVICE NEEDS:

- FIRE DETECTION IS REQUIRED AT EARLIEST STAGE OF EVENT
- RAPID RESPONSE OVERHEAT AND INCIPIENT CONDITION DETECTORS
- LOW-GRAVITY DATA BASE NEEDS:
  - FLAME CHARACTERISTICS
  - SMOKE PARTICLE SIZE AND SIZE DISTRIBUTION
  - DETECTABLE AEROSOLS DUE TO OVERHEAT
- MEANS FOR MINIMIZATION OF FALSE ALARMS:
  - EXPERT SYSTEMS REQUIRED
  - SPECIAL SYSTEMS FOR CREW ALERTING
  - ARTIFICIAL FIRE SIGNATURE GENERATORS

FIRE EXTINGUISHANTS AND SYSTEMS:

- MUST BE COMPATIBLE WITH SPACECRAFT SYSTEMS
- MUST BE EFFECTIVE ON ALL FIRE SCENARIOS INCLUDING HYPERBARIC REGIONS
- DATA BASE REQUIRED FOR EXTINGUISHANT USE:
  - SEVERITY OF TOXIC PRODUCTS RESULTING FROM VARIOUS FIRE INTERACTION SCENARIOS
  - EFFECTIVENESS OF EXTINGUISHANTS VERSUS FLAME TEMPERATURE AND OXYGEN CONCENTRATION

IN-SPACE EXPERIMENTATION NEEDS

LOW-GRAVITY IGNITION AND FLAME SPREAD:

- INVESTIGATE MATERIAL IGNITABILITY
- FOR SELECTED MATERIALS, DETERMINE FLAME SPREAD RATES AND EXTINCTION LIMITS FOR VARIOUS ENVIRONMENTS
- ASSESS POTENTIAL HAZARD FOR SPONTANEOUS COMBUSTION OF PARTICLE CLOUDS
- ASSESS FIRE HAZARDS ASSOCIATED WITH FLAMMABLE LIQUID SPILLS

FIRE DETECTION IN LOW GRAVITY:

- DEVELOP A DATA BASE OF FIRE SIGNATURES IN LOW GRAVITY:
  - INVESTIGATE FLAME CHARACTERISTICS
  - EVAULATE LOW-GRAVITY EFFECTS ON SMOKE PRODUCTION
- TEST NEW DETECTORS IN LOW-GRAVITY USING REAL AND ARTIFICIAL FIRE SIGNATURES

IN-SPACE EXPERIMENTATION NEEDS

FIRE EXTINGUISHMENT:

- •INVESTIGATE EFFECTIVENESS IN LOW-GRAVITY
  - -ASSESS EFFECTIVENESS/HAZARD WHEN USED IN HYPERBARIC REGIONS
  - -SAFE FOR CREW AND COMPATIBLE WITH SYSTEMS?
- •ESTABLISH DATA BASE FOR FIRE/EXTINGUISHANT INTERACTION
  - -MAP EXTINGUISHANT EFFECTIVENESS VERSUS FLAME TEMPERATURE
  - -EVALUATE EFFECTIVENESS ON SMOLDERING COMBUSTION

POST-FIRE CLEANUP:

- •DEVELOP MEANS FOR EFFECTIVE PICK UP OF SMOKE PARTICLES AND AEROSOLS REMAINING AFTER AN EVENT
- •EVALUATE EFFECTS OF COMBUSTION/EXTINGUISHANT PRODUCTS ON ELECTRONIC GEAR

FIRE SAFETY EXPERIMENT CONCEPTS:

- •EXPERIMENTS GENERALLY NEED TO BE COMPACT/MULTI-PURPOSE
- •ATTEMPT TO MAXIMIZE DATA OBTAINED
- •PLAN TO ATTEND NASA LEWIS SPONSORED WORKSHOP:
  - -INTERNATIONAL MICROGRAVITY COMBUSTION WORKSHOP
  - -DATE: JANUARY 25 & 26, 1989

MAINTENANCE, SERVICING & REPAIR

IN

SPACE

BOB DELLACAMERA

TELEPHONE: (714)896-5224

MCDONNELL DOUGLAS

SPACE SYSTEMS COMPANY

INTRODUCTION/BACKGROUND

- MAINTENANCE, SERVICING & REPAIR HAS BEEN DONE IN SPACE
- MANNED MAINTENANCE & REPAIR SO FAR
- EXTREMELY PLANNED OR UNPLANNED
- NOT NORMALLY BASELINED

MISSION APPLICATIONS

- ALL MISSIONS CAN BENEFIT FROM INCLUDING MAINTENANCE SERVICING AND REPAIR PROVISIONS
  - SOFTWARE
  - HARDWARE
  - REPLENISHMENT

- EVA IS NOT THE ONLY THE ONLY METHOD OF MAINTENANCE, SERVICING & REPAIR

- MAINTENANCE, SERVICING & REPAIR REQUIRES A SUPPORT INFRASTRUCTURE FOR FULL IMPLEMENTATION

TECHNOLOGY NEEDS

DEVELOP TECHNOLOGIES FOR SUPPORTING INFRASTRUCTURE

- ROBOTICS
  - COGNITIVE CAPABILITIES
  - SERVICE ROBOTS
- COMPOSITE REPAIR
  - TRUSS
  - PRESSURE SHELLS
- TECHNICAL DATA
  - FORMAT/ACCESS
  - PRESENTATION/STORAGE
  - UPDATES
- EVA SUITS
  - SPACE BASING
  - MORE HARDNESS
  - LESS MAINTENANCE
- CONSUMMABLES
  - CRYO PUMPING
  - CRYO STORAGE
    - * INSULATION
    - * RELIQUIFACTION
  - TOXIC FLUIDS
  - DECONTAMINATE THE REFUELER

IN-SPACE EXPERIMENT NEEDS/VOIDS

- INSTITUTIONALIZE MAINTENANCE, SERVICING & REPAIR BY DEMONSTRATION

  -MANNED -ROBOTIC
  -COMBINATION

- MAINTAIN,SERVICE & REPAIR AT HIGH INCLINATION AND POLAR ORBITS

- DEMONSTRATE MAINTENANCE, SERVICING & REPAIR HARDWARE FOR:

  -REFUELING
  -SELF-CONTROLLED ROBOTS
  -MANNED POLAR OPERATIONS

IN-SPACE EXPERIMENT RECOMMENDATION

- ALL SPACE SYSTEMS SHOULD DEMONSTRATE MAINTENANCE, SERVICING & REPAIR CONCEPTS AS PART OF DEVELOPING THE BASIC MISSION CONCEPT
- APPLY ROBOTICS TO MAINTENANCE, SERVICING & REPAIR PROBLEMS SOON
- MAINTAIN AND REPAIR A ROBOTIC SERVICER ON-ORBIT
- FLY A PROTOTYPE HARD SUIT AT HIGH INCLINATIONS
- DEVELOP A SMALL-SCALE LONG DURATION REFUELING PILOT PLANT(CRYO,STORABLE)
- REFUEL SPACECRAFT ON-ORBIT

7.3 PAYLOAD OPERATIONS

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PAYLOAD OPERATIONS

FROM THE PERSPECTIVE OF

MANNED SPACEFLIGHT

DR. JEFFREY A. HOFFMAN

ASTRONAUT OFFICE

NASA-JOHNSON SPACE CENTER

HOUSTON, TX

INTRODUCTION

- HISTORICALLY, THE BUSINESS OF ASTRONAUTS WAS TO GET THEIR SPACECRAFT TO ITS DESTINATION AND BACK AGAIN.

- SINCE SKYLAB, ASTRONAUTS HAVE HAD TIME IN ORBIT TO CARRY OUT EXTENSIVE PAYLOAD-ORIENTED OPERATIONS.

- SPACE STATION WILL CONTINUE THIS TRADITION.

- SPACE SHUTTLE FLIGHTS CARRY SUFFICIENT NUMBER OF CREW MEMBERS TO ALLOW SOME ASTRONAUTS TO BE DEVOTED TO PAYLOAD ACTIVITIES.
  - EVA
  - RMS
  - DEPLOYMENTS
  - SCIENTIFIC INVESTIGATIONS

MISSION APPLICATIONS

HIGH GROUND

- VIEW DOWN
  - METEOROLOGY
  - EARTH RESOURCES
  - OCEANOGRAPHY
  - ETC.
  - SYNERGISM BETWEEN SATELLITES AND CREW PHOTOGRAPHY
  - SPACE STATION LIMITED BY 28° ORBIT
- VIEW UP - IR, UV, X, GAMMA RAY ASTRONOMY
  - BEST SUITED FOR UNMANNED VEHICLES
  - FOR FUTURE PAYLOAD OPERATIONS, NEED HONEST TRADE STUDY BETWEEN COST OF MAINTAINABILITY AND COST OF FAILURES
- VIEW AROUND - PLASMA, AURORAL AND IONOSPHERIC STUDIES
  - COMBINE GEO, LEO AND GROUND STUDIES
  - TETHERS, UP AND DOWN, OFFER NEW METHODS OF STUDY

TECHNOLOGY NEEDS

HIGH GROUND

1) ABILITY TO DEAL WITH EVER-INCREASING AMOUNTS OF DATA

2) TEST TETHER TECHNOLOGY

3) DEVELOP SATELLITE REPAIR, REFURBISHMENT AND REFUELING

MISSION APPLICATIONS

MICROGRAVITY

- HUMAN RESPONSE TO SPACE
  - THE ENVIRONMENT CREATES ITS OWN FIELD OF STUDY

- FUNDAMENTAL RESEARCH
  - FLUID PHYSICS
  - MATERIAL PROPERTIES
  - CRYSTAL GROWTH
  - BOTANY/ZOOLOGY

- APPLICATIONS
  - FIRE RESEARCH
  - EVENTUAL PRODUCTION PROCESSES

OVERWHELMING TECHNOLOGICAL NEED: **ABILITY TO USE SPACE AS A UNIQUE LABORATORY**

TECHNOLOGY NEEDS

USE OF SPACE AS A LABORATORY

- MUST BALANCE UNIQUENESS OF ENVIRONMENT AGAINST OUR ACCUMULATED KNOWLEDGE OF HOW TO OPERATE IN A LAB.
- INTERACTIVE CREW OPERATIONS VS. AUTOMATION
  - USE OF HUMANS IS MOST VALUABLE DURING EARLY STAGES OF INVESTIGATIONS.
  - INCREASED UNDERSTANDING OF μ-g PHENOMENA ALLOWS INCREASED USE OF AUTOMATION TO CREATE GREATER EFFICIENCY.
- EFFICIENT USE OF CREW TIME IS UNIQUE TO SPACE ENVIRONMENT
  - SPACE STATION MAY HAVE LESS CREW TIME THAN SHUTTLE
  - OBSERVE EXPERIMENTS IN PROGRESS
  - CHANGE PROTOCOL WHERE NECESSARY
  - REPAIR OR ALTER HARDWARE
- CLOSE UNION OF SCIENTIFIC ACTIVITIES ON GROUND AND ORBIT IS ESSENTIAL

→ **TELESCIENCE**

TECHNOLOGY NEEDS

TELESCIENCE

- HIGH DENSITY DATA AND COMMAND LINKS FOR GROUND OPERATIONS
  - VARIABLE FORMAT TV: RESOLUTION VS. SPEED VS. COLOR.
- EXPERIMENT DESIGN TO ALLOW EFFICIENT USE OF ONBOARD CREW
  - VISIBILITY
  - ACCESSIBILITY
- MAXIMIZE ABILITY TO REPEAT EXPERIMENTS AND ALTER VARIABLES.
- EXPERT SYSTEMS TO ASSIST CREW AND GROUND.
- FOR MATERIALS SCIENCE, SAMPLE RETURN CAPABILITY (SPACEMAIL).

SUMMARY

- BALANCE BETWEEN SCIENTIFIC RESERCH AND SPACEFLIGHT OPERATIONS

- EARLY INVOLVEMENT OF CREW CAN ENHANCE EXPERIMENTS

ORBIT ASSEMBLY NODE

TOM STYCZYNSKI
LEE R. LUNSFORD

LOCKHEED MISSILES & SPACE CO., INC.
SUNNYVALE, CA.

INTRODUCTION / BACKGROUND

OBJECTIVE: ASSEMBLY, VERIFICATION, SERVICING, REPAIR & CORRECTION, AND REFURBISHMENT.

MISSIONS:

* PLANETARY EXPLORATION MISSIONS - UNMANNED: PRECURSOR MISSION TO PLANETS AND MOONS WITHIN THE SOLAR SYSTEM.

* PLANETARY EXPLORATION MISSIONS - MANNED: LARGE TRANSIT VEHICLES, REFUELING & REFURBISHMENT STATIONS, etc.

* MISSION TO PLANET EARTH - ASSEMBLY AND TRANSFER OF VEHICLES TO SYN-EQ.

* LARGE SOLAR ELECTRIC ENERGY SYSTEMS.

* SPACE BASED MANUFACTURING & SERVICE FACILITIES.

TECHNOLOGY NEEDS
ORBIT ASSEMBLY AREA CONCEPT

CRITICAL FUNCTIONS

* PRECISION SCHEDULING.
* SELF-CONTAINED, AUTONOMOUS CHECK-OUT AND HEALTH STATUS.
* AUTONOMOUS STABILIZATION FOR ASSEMBLY OF ADDITIONS COMPONENTS, ETC. - docking, berthing, positioning, orientation.
* PRECISION PLACEMENT: MICRO NAVIGATION, PRECISION ALIGNMENT AND ORIENTATION
* VISION CONTROL - focus, alignment, field of view, and shielding from the sun.
* AUTONOMOUS ASSEMBLY (ROBOT ASSEMBLY), TELE-ROBOTIC ASSEMBLY, & EVA ASSEMBLY.
* FUELING OR TOPPING OFF - PROPELLANT DEPOT OR TANKER
* PROTECTION OR HARDENING OF ASSEMBLY FROM SPACE DEBRIS AND SOLAR ILLUMINATION.
* VERIFICATION OF PROPER ASSEMBLY - PNEUMATIC, STRUCTURAL, etc.

IN-SPACE EXPERIMENTATION NEEDS/VOIDS

AUTONOMOUS CHECK-OUT:

SELF CONTAINED, AUTONOMOUS CHECK-OUT AND HEALTH STATUS WITH CAPABILITY FOR AUTONOMOUS INTEGRATION INTO THE NEXT HIGHER UNIT. CONCEPT SHOULD INCLUDE ACTIVATION OF THE AUTONOMOUS SYSTEM AT SHIPMENT FROM THE FACTORY. NETWORKING AND SOFTWARE SHOULD PROVIDE CONTINUOUS READOUT (i.e., 10 TIMES PER SECOND).

CRITICAL TECHNOLOGIES: - SENSORS, NETWORKING, & SOFTWARE:

* SENSORS REQUIREMENTS INCLUDE: ELECTRICAL, ELECTRONIC, STRUCTURES, MECHANICAL (i.e., LOCKED OR UNLOCKED), POSITION, LEAKAGE, PRESSURE, EXPENDABLES AVAILABLE (i.e., ZERO "G" MEASURE OF REMAINING PROPELLANTS), TEMPERATURE, VIBRATION & SOUND/PRESSURE LEVELS, STRESS & STRAIN, AND SEQUENCE OF EVENTS.

* NETWORKING: POWER, DATA AND COMMAND NETWORKING WILL BE REQUIRED WITH CAPABILITY OF AUTONOMOUS INTEGRATION INTO THE NEXT HIGHER UNIT UPON ASSEMBLY - BOTH HARDWARE AND SOFTWARE PROBLEM.

* SOFTWARE: COMMAND AND CONTROL, SENSOR DATA PROCESS & EVALUATION, REPORTING CRITERIA (i.e., RECORD EVENT, REPORT EVENT, OR SOUND ALARM).

IN-SPACE EXPERIMENTATION NEEDS/VOIDS

AUTONOMOUS PLACEMENT:

AUTONOMOUS ACQUISITION, RECOGNITION/IDENTIFICATION, LOCATION, GRASPING OR MATING, PRECISION PLACEMENT OR INSERTION AND ASSEMBLY.

CRITICAL TECHNOLOGIES:

* VISION: ACQUISITION, RECOGNITION/IDENTIFICATION, LOCATION, EVALUATION AND CONTROL
* AUTONOMOUS STABILIZATION FOR ASSEMBLY: STABILIZATION DURING DOCKING, BERTHING, POSITIONING, AND ORIENTATION FOR ASSEMBLY.
* MICRO-NAVIGATION: TO SUPPORT PRECISION PLACEMENT, INSERTION, OR LOCATION OF DEFECTIVE PART.
* PRECISION ATTITUDE DETERMINATION AND CONTROL: TO SUPPORT LOCATION AND IDENTIFICATION, PLACEMENT AND ORIENTATION.
* VERIFICATION: VERIFICATION OF ASSEMBLY TO INCLUDE MECHANICAL, ELECTRICAL, ELECTRONIC, PNEUMATIC, HYDRAULIC, STRUCTURAL, POSITION LOCATION & ORIENTATION.
* END EFFECTORS: FOR GRASPING, HOLDING, MANIPULATING, POSITIONING, ORIENTING, AND INSERTING.

IN-SPACE EXPERIMENTATION NEEDS/VOIDS

AUTONOMOUS REPLACEMENT OF PARTS:

AUTONOMOUS ACQUISITION, RECOGNITION/IDENTIFICATION, LOCATION, GRASPING OR ATTACHMENT, OPENING OF COVER OR PANELING, LOCATION, GRASPING & REMOVAL OF DEFECTIVE PART, FOLLOWED BY INSERTION OF REPLACEMENT PART, CLOSING OF COVER OR PANEL, AND VERIFICATION OF PERFORMANCE. REPEAT FOR ELECTRICAL/ELECTRONIC PARTS, PNEUMATIC PARTS, HYDRAULIC (i.e., PROPELLANT) PARTS, AND MECHANICAL COMPONENTS.

CRITICAL TECHNOLOGIES:

* DEVELOPMENT OF COMPATIBLE ASSEMBLY COMPONENTS AND ROBOT CONCEPTS.
* HIGHER LEVEL OF AUTOMATION, FORCE FEEDBACK END EFFECTORS, ETC.
* SELF-LOCATION, ORIENTATION, MICRO NAVIGATION.
* VISION SYSTEM CAPABLE OF SENSING PLACEMENT OR INSERTION ACTIVITY IN A CLOSED LOOP.
* POSITIONING AND ORIENTATION.
* VERIFICATION OF PERFORMANCE - i.e., UNLOCKING, & LOCKING.

SUMMARY / RECOMMENDATIONS

* SYSTEM TRADES:
  - ASSEMBLY FACILITY VS. ASSEMBLY AREA WITH ENHANCED SPACE STATION
  - ORBITAL PROPELLANT DEPOT VS. TRANSPORT WITH PROPELLANT & TOP OFF FROM TANKER
* CRITICAL TECHNOLOGIES:
  - NETWORKING, SOFTWARE, & SENSORS FOR AUTONOMOUS CHECK-OUT AND HEALTH STATUS.
  - VISION CONTROL - CLOSED LOOP ACQ., RECOGNITION, LOCATION, & EVALUATION.
  - PRECISION PLACEMENT - MICRO NAVIGATION, PRECISION ATTITUDE CONTROL, AUTONOMOUS STABILIZATION TO SUPPORT PLACEMENT.
  - VERIFICATION OF ASSEMBLY FUNCTIONS.
* IN-SPACE EXPERIMENTATION
  - SELF CONTAINED CHECK-OUT AND HEALTH STATUS WITH CAPABILITY OF INTEGRATION INTO THE NEXT HIGHER UNIT.
  - AUTONOMOUS PRECISION PLACEMENT AND ASSEMBLY
  - AUTONOMOUS REPLACEMENT OF COMPONENTS & SUB-ASSEMBLIES

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IN-SPACE SYSTEMS: SPACE CONSTRUCTION AND PAYLOAD OPERATIONS

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Boulder, Colorado

INTRODUCTION/BACKGROUND

- Humanity is entering 2nd ERA of the Space Age:

  1st Era:
  - Space flight realization, 1957-1987

  2nd Era:
  - Space exploration and base activation, 1987-2027

  3rd Era:
  - Space colonization and utilization, 2027--

- Parallel to man's Arctic and Antarctic activities:
  Visit the Poles; Establish scientific bases; Alaskan pipeline; Canadian Arctic Center

- Long-term Space Mission Planning--many destinations, many decades:
  - National Commission on Space Report, 1986
  - Dr. Sally Ride's Report, 1987
  - NASA's Pathfinder Program
  - President Reagan's National Space Policy, 1988

  Consensus: Explore and utilize the Solar System; develop space commercially.

- Space Program Philosophy:
  - Building Block Approach;
  - International participation;
  - Mission model optimization, not single mission optimization only.

MISSION APPLICATIONS

- Mission Model Identified:
    - Large unmanned laboratories, antenna arrays, telescopes, etc.
    - Mission to Planet Earth (Remote Sensing)
    - Space Stations and Platforms
    - On-orbit Assembly of Manned Interplanetary Spacecraft
    - Lunar Base
    - Mars Base
- Demands for increased scientific data operations
- Space construction instead of delivering entire space structure at one launch
- Astronaut work limitations
- Astronaut environmental protection required

TECHNOLOGY NEEDS

- Orbital logistics needs - Determine optimum mix of launch vehicles: large vs small, unmanned vs man-rated

- Telecommunication needs:

  - Construction phase telecommunication
  - improve telecommunication for operations and experiment telescience (OASIS)

- In-space Construction and Operation needs:

  - Type and intelligence (autonomy) of robots?
  - Bionic devices for astronauts?
  - Optimum astronaut/robot mix?

- Space Environment protection needs:

  - meteoroid/debris
  - radiation
  - thermal
  - pressure

SPACE TELECOMMUNICATIONS EXPERIMENTS FOR CONSTRUCTION/OPERATIONS

- The time-delay problem
- The security blanket problem
- The Steady-State Telecommunications System design problem
- The emergency support problem: equipment failure/medical crisis-- AI implications
- The Tower of Babel Problem

IN-SPACE EXPERIMENTATION NEEDS/VOIDS

- Telecommunications System
  - Develop and test Telecommunications System for Space Construction Phase
  - Experiment with time-delay command-control
- OASIS system development and test (for operating space experiments)
- ET Space Experiments:
  - Lower-Thermosphere Density Experiment
  - Space Meteoroid/Debris monitoring experiment
  - Fluid vibration generation experiment
  - Space thruster experiment
  - Explosive fastening experiment
- Macro-Planning Model Development

SUMMARY AND RECOMMENDATIONS

- Plans for Space Construction Needs as well as Space Operations Needs.
- Develop standardized Construction-Phase and Steady-State Telecommunications for transmission of voice, video, data, computer, teleoperators commands in presence of time delays.
- Develop and Test a 1990's, user-friendly, teleoperator/telescience work-station, e.g., OASIS.
- Utilize the ET as well as ELV's and Shuttle Orbiter to provide knowledge of Space Environment.
- Develop a Macro-Planning Model for optimizing planning of a multi-year, multi-destination Space Program Mission Model.

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IN-SPACE SYSTEMS
CRITICAL TECHNOLOGY REQUIREMENTS

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IN-SPACE SYSTEMS THEME

<u>THEME ELEMENTS</u>

- MATERIALS PROCESSING

- MAINTENANCE, REPAIR, AND FIRE SAFETY

- PAYLOAD OPERATIONS

MATERIALS PROCESSING

AN ALL ENCOMPASSING DEFINITION OF MATERIALS IS USED IN THIS ELEMENT.

MATERIALS PROCESSING

PRIORITY:

1. UNDERSTANDING OF MATERIALS BEHAVIOR IN SPACE ENVIRONMENT

2. DEMONSTRATION OF INNOVATIVE IN-SPACE SAMPLE ANALYSIS TECHNIQUES

2. CHARACTERIZATION AND MANAGEMENT OF THE MICRO-G ENVIRONMENT

3. DEMONSTRATION OF IMPROVED SENSING AND IMAGING TECHNIQUES IN EXPERIMENTAL SYSTEMS

4. DEMONSTRATION OF AUTOMATION AND ROBOTICS APPLICATIONS TO MATERIAL PROCESSING SYSTEMS

CONSENSUS CONCERN:

WASTE PRODUCTS FROM MATERIAL PROCESSING

EXPLANATION OF MATERIALS PROCESSING NEEDS

- UNDERSTANDING OF MATERIALS BEHAVIOR IN SPACE ENVIRONMENT. SPACE ENVIRONMENT INCLUDES MICRO-G AND / OR ULTRA HIGH VACUUM. WE ARE ESPECIALLY CONCERNED WITH UNDERSTANDING A RANGE OF DYNAMIC PROCESSES IN MICRO-G, INCLUDING (BUT NOT LIMITED TO):
  - THERMOCAPILLARY FLOW
  - GAS/LIQUID/SOLID PHASE SEPARATION AND INTERFACE BEHAVIOR
  - DIFFUSION AND PERMEABILITY
  - WETTING
- DEMONSTRATION OF INNOVATIVE IN-SPACE SAMPLE ANALYSIS TECHNIQUES. THESE SAMPLE ANALYSIS TECHNIQUES SHOULD FOCUS ON REDUCING THE SIZE, MASS AND/OR HAZARDS OF CONVENTIONAL TECHNIQUES SUCH AS SCANNING ELECTRON MICROSCOPE, X-RAY FLUORESCENCE, WET CHEMICAL PROCESSING AND THE LIKE.
- CHARACTERIZATION AND MANAGEMENT OF THE MICRO-G ENVIRONMENT. IN PARTICULAR THERE IS A CRITICAL NEED FOR IN SITU MEASUREMENT OF G LEVELS FROM 10^{5} G TO 10^{-8} G AT FREQUENCIES <1 Hz ; PASSIVE AND ACTIVE VIBRATION ISOLATION AT LOW FREQUENCIES, AND THE REALISTIC ASSESSMENT OF G-LEVEL REQUIREMENTS FOR BIOLOGICAL AND PHYSICAL EXPERIMENTS.
- DEMONSTRATION OF IMPROVED SENSING AND IMAGING TECHNIQUES IN EXPERIMENTAL SYSTEMS. WE NEED TO DEVELOP AND DEMONSTRATE ENABLING TECHNOLOGIES WHICH ALLOW FOR REAL-TIME MONITORING, NON-CONTACT TEMPERATURE MEASUREMENT, MINIATURIZATION OF SENSORS AND IMPROVED IMAGE ANALYSIS.
- DEMONSTRATION OF AUTOMATION AND ROBOTIC APPLICATIONS TO MATERIAL PROCESSING SYSTEMS. THERE IS A NEED FOR DEVELOPMENT OF EXPERT SYSTEMS AND REACTIONLESS ROBOTS FOR MATERIALS PROCESSING.

MAINTENANCE, REPAIR AND FIRE SAFETY

PRIORITY:

1. DEMONSTRATION AND VALIDATION OF CAPABILITY TO REPAIR UNEXPECTED EVENTS

1. INVESTIGATION OF LOW-G IGNITION, FLAMMABILITY/FLAME SPREAD AND FLAME CHARACTERISTICS

2. DEMONSTRATION AND VALIDATION OF FLUID REPLENISHMENT TECHNIQUES

2. UNDERSTAND BEHAVIOR OF FLAME EXTINQUISHANTS IN SPACE ENVIRONMENT

3. DEMONSTRATE ROBOTIC MAINTENANCE AND REPAIR CAPABILITY

CONSENSUS INTERESTING IDEA:
SIMULATED ACCIDENT SCENARIOS

PAYLOAD OPERATIONS

PRIORITY:

1. DEMONSTRATION AND VALIDATION OF TELESCIENCE TECHNIQUES

2. DEMONSTRATION OF AUTONOMOUS CHECKOUT, PLACEMENT AND SPACE CONSTRUCTION

CONSENSUS CONCERNS:

- RAPID SAMPLE RETURN
- ORBITAL DEBRIS

8. HUMANS IN SPACE

HUMANS IN SPACE
BACKGROUND AND OBJECTIVES

REMUS BRETOI
AMES RESEARCH CENTER

HUMANS IN SPACE

THEME OVERVIEW

THEME SESSION OBJECTIVES

DESCRIPTION OF THEME & THEME ELEMENTS

BACKGROUND OF THEME TECHNOLOGY DEVELOPMENT

PROGRESS SINCE 1985 WORKSHOP

THEME SESSION AGENDA

PRIORITIZATION CRITERIA

SUMMARY

HUMANS IN SPACE

THEME SESSION OBJECTIVES

PURPOSE

- Identify & Prioritize In-Space Technologies for Humans In Space Which:

  Are Critical for Our Future Space Programs, & Need Development & In-Space Validation.

- Obtain Aerospace Community Comments & Suggestions on OAST IN-STEP Plans

PRODUCT

Aerospace Community Recommended Priority Listing of Critical Space Technology Needs & Associated Space Flight Experiments

HUMANS IN SPACE

DESCRIPTION OF THEME & THEME ELEMENTS

EVA/SUIT

HUMAN PERFORMANCE

CLOSED-LOOP LIFE SUPPORT SYSTEMS

HUMANS IN SPACE

EVA/SUIT

SUITS & EQUIPMENT

Pressure Suit Technology
Glove Technology
End-Effector Technology
Mobility Aids
Tools
Displays & Controls
Interfaces

PORTABLE LIFE SUPPORT SYSTEMS

Thermal Control
Atmosphere Control
Automated Control Technology
Display Technology
Regeneration Equipment

HUMANS IN SPACE

EVA/SUIT
(Continued)

LOGISTICS & SUPPORT

Diagnostics
Displays & Controls
Maintenance & Repair
Inventory Management & Supply
Information Management

HUMANS IN SPACE

HUMAN PERFORMANCE

CREW & ENVIRONMENTAL FACTORS

Organization and Management
Crew Coordination
Environmental & Mission Task
Training and Intervention

HUMAN-MACHINE INTERACTION

Crew Support and Enhancement
Human-Automation-Robotics (HAR)

HUMANS IN SPACE

HUMAN PERFORMANCE
(Continued)

ARTIFICIAL GRAVITY & ADV. COUNTERMEASURES

ARTIFICIAL GRAVITY

Rotation Rate
Intermittent G vs Continuous Exposure
Partial G and G Threshold
Structural Facility Impact

ADVANCED COUNTERMEASURES

Electromyostimulation
Pharmacological Tests
Autogenic Feedback
Pre-Adaptation Training

NASA Ames Research Center

HUMANS IN SPACE

CLOSED-LOOP LIFE SUPPORT SYSTEMS

PHYSICAL/CHEMICAL CLOSED-LOOP LIFE SUPPORT

Water Reclamation
Waste Management
Thermal Control
Monitoring & Control Instrumentation
Air Revitalization

HUMANS IN SPACE

THEME BACKGROUND

TECHNOLOGY DEVELOPMENT

HUMANS IN SPACE was not a theme in the 1985 Workshop. It is a new addition to the IN-STEP / Outreach Program.

RELATED STUDY EFFORTS resulting from the 1985 Workshop were:

- Spatial Perception Auditory Referencing
- Microbiology Monitor
- Closed-Loop Nutrient Solution Delivery System
- Water Electrolysis Operation

HUMANS IN SPACE

AGENDA

Wednesday December 7th

CRITICAL SPACE TECHNOLOGY & IN-SPACE EXPERIMENTS NEEDS

(PRESENTATIONS and DISCUSSIONS))

EVA/SUIT PRESENTATIONS

Bruce W. Webbon / Bernadette Squire (NASA-ARC)
H. Thomas Fisher (Lockheed Corporation)
David L. Akin (MIT, Aeronautics and Astronautics Dept)

EVA/SUIT OPEN DISCUSSION

Questions & Answers With Speakers
Identification of Additional Technologies/Experiments

NASA Ames Research Center

HUMANS IN SPACE

AGENDA

WEDNESDAY DECEMBER 7th

HUMAN PERFORMANCE PRESENTATIONS

Barbara Kanki (NASA-Ames Research Center)

Lawrence G. Lemke (NASA-HQ / Office of Exploration)

Wm. Russell Ferrell (University of Arizona, Tucson)

HUMAN PERFORMANCE OPEN DISCUSSION

Questions & Answers With Speakers

Identification of Additional Technologies/Experiments

HUMANS IN SPACE

AGENDA

WEDNESDAY DECEMBER 7th

CLOSED-LOOP LIFE SUPPORT SYSTEMS PRESENTATIONS

Robert D. MacElroy (NASA - Ames Research Center)

Richard L. Olson/Thomas J. Slavin (Boeing Aerospace)

Marvin Luttges (University of Colorado, Boulder)

CLOSED-LOOP LIFE SUPPORT SYSTEMS OPEN

Questions & Answers With Speakers

Identification of Additional Technologies/Experiments

HUMANS IN SPACE

AGENDA

THURSDAY, DECEMBER 8th

PRIORITIZE CRITICAL TECHNOLOGIES (AUDIENCE)

COMBINE & PRIORITIZE THEME TECHNOLOGIES

FRIDAY DECEMBER 9th

THEME LEADER PRESENTATIONS TO GENERAL SESSION

WORKSHOP WRAP-UP

PRIORITIZATION CRITERIA*

1. **CRITICAL ENABLING TECHNOLOGIES**
   Technologies critical for future space missions

2. **COST REDUCTION TECHNOLOGIES**
   Technologies which can decrease costs or complexity (e.g., development, opns, life-cycle)

3. **BROAD APPLICATION TECHNOLOGIES**
   Technologies which can improve or enhance a variety of space missions

4. **REQUIRE IN-SPACE VALIDATION**
   Technologies which require the space environment or micro-gravity for validation or experimentation

* CRITERIA ARE LISTED IN ORDER OF IMPORTANCE (1 IS HIGHEST)

8.1 EVA/SUIT

EVA TECHNOLOGY

DR. BRUCE W. WEBBON, Ph.D.
BERNADETTE SQUIRE

NASA-Ames Research Center
Crew Research and Space Human Factors Branch

INTRODUCTION/BACKGROUND

CURRENT EVA SYSTEM LIMITATIONS

- Low working pressures (productivity impacts)
- Limited mobility
- Marginal crew comfort
- Marginal glove acceptability
- Large consumable mass
- Maintenance and servicing
- Protection from environmental hazards
- Bends risk
- High life-cycle costs
- Growth potential
- Working period limitations
- Sizing repeatability

TECHNOLOGY NEEDS

SYSTEMS STUDIES

- MISSION REQUIREMENTS DEFINITION

  Environmental, Task, Design Reference Mission

- HUMAN REQUIREMENTS DEFINITION

  Human Factors, Physiological, Medical

- EVA WORK SYSTEMS INTEGRATION

  Modeling, Trade Studies, Interface Definition, Logistics, Support, Test Requirements

TECHNOLOGY NEEDS

PORTABLE LIFE SUPPORT SYSTEM (PLSS)

- THERMAL CONTROL SYSTEMS
  Heat Storage, Acquisition, Transport, Rejection
- ATMOSPHERE CONTROL
  O_2 Supply, CO_2 Control, Trace Contaminant Control, Humidity Control
- MONITORING & CONTROL
  Automated Control, Display Technology
- SYSTEM INTEGRATION
  Support Equipment and Interfaces

TECHNOLOGY NEEDS

EVA SUITS & EQUIPMENT

- PRESSURE SUIT TECHNOLOGY
  - Materials, Structures, Components, Mobility Elements
- GLOVES & END-EFFECTORS
- EVA ANCILLARY EQUIPMENT
  - Mobility Aids, Tools, Displays & Controls, Work System Interfaces
- SYSTEM INTEGRATION & TEST
  - Logistics & Support

SUMMARY / RECOMMENDATIONS

Determine (empirically):

EVA Physiological/Metabolic Parameters
Thermal Environment Parameters

Characterize:

EVA Biomechanics in Reduced-g
g-Sensitivity of Phase Change Processes

Demonstrate:

Radiation Protection (Mars Transit)
Radiator/Refrigeration System
Electrochemical Regeneration of CO_2
Voice Technology for Control Applications
Countermeasures for Bearing Blocking, Cold Welding
Advanced Pressure Suit Technology in Zero-g
High Pressure Gloves
End-Effector Use in EVA Tasks

IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP

DEC. 6-9, 1988

ATLANTA, GEORGIA

SPONSORED BY NASA-OAST

HUMANS IN SPACE (EXTRA-VEHICULAR ACTIVITY/SUIT)

Presentation By

H. T. Fisher
Space Station Program
Astronautics Division
Lockheed Missiles & Space Co.

INTRODUCTION/BACKGROUND

1. THERE IS NO DOUBT EVA IS A CRITICAL TECHNOLOGY TO NASA CURRENT SPACE ACTIVITIES AND FUTURE MISSION PLANS
2. EVA HAS UNIVERSIAL APPLICABILITY & MULTI-MISSION UTILITY
3. PRESENT EVA TECHNOLOGY IS EVOLVING TO ENHANCE:
   - CREW PRODUCTIVITY
   - RISK REDUCTION
   - MISSION FLEXIBILITY
   - ALTERNATIVE PATHS
4. NASA & DoD MAY SHARE COMMON NEEDS - E.G., CANDIDATE DoD MILITARY MANNED SPACE OPERATIONS
5. CERTAIN EVA TECHNOLOGIES ARE WELL UNDERWAY WHILE OTHERS ARE LAGGING OR ARE NOT BEING WORKED
6. MOST ADVANCED EVA PROGRAM EFFORT IS WITHIN THE NASA WITH LITTLE AEROSPACE/COMMERCIAL INDEPENDENT VENTURES
7. LIMITED, BUT IMPORTANT ADVANCED EVA PLANETARY STUDY WORK IS JUST BEING INITIATED & MORE IS PLANNED (?) VIA PATHFINDER - NASA-JSC/AMES
8. *IT APPEARS PRUDENT TO RE-ASSESS WHERE EVA TECHNOLOGY IS HEADED*

EVA TECHNOLOGY NEEDS - SELECTED

EVA ENCLOSURE & LIFE SUPPORT

- EXTENDED PERSONAL LIFE SUPPORT SYSTEM DURATION
- RAPID CREW 'IN-SITU' SUIT SERVICING
- PROTECTION AGAINST RADIATION HAZARDS
- RAPID EVA ACCESS - LSS COMPATIBILITY WITH S/C
- ENHANCED AUDIO/HEADS-UP DISPLAY & WRIST CUFF

EVA SUPPORT EQUIPMENT

- SMALL LT-WT PORTABLE HYPERBARIC TREATMENT UNIT
- SMALL LT-WT PORTABLE AIRLOCK
- SMALL LT-WT PORTABLE SURFACE TRANSPORTER (EV CREW/EQUIP)
- SMALL LT-WT PORTABLE RADIATION/THERMAL/WIND SHELTER
- MULTI-PURPOSE EVA WORK STA. & MOTORIZED FOOT RESTRAINT
- CREW & EQUIP TRANSPORTER & POSITIONING AID
- CREW & EQUIPMENT RECOVERY/RETRIEVAL UNIT
- ADVANCED MANEUVERING UNIT
- EMERGENCY SUIT 'LIFE JACKET'
- EMERGENCY EVA SURVIVAL GEAR
- SUIT CONTAMINATION DETECTION & CLEANING UNIT
- DEBRIS/LOOSE EQUIP. HANDLING AIDS/STOWAGE UNITS
- ADVANCED POWER TOOLS FOR EVA
- PORTABLE EVA EXPER/SURVEY/SAMPLE KIT
- PORTABLE MULTI-PURPOSE AVIONIC UNIT

EVA TECHNOLOGY NEEDS - DEVELOPMENT FACTORS

DEVELOPMENT FACTORS → / DEVELOPMENT ELEMENTS	FUNDING LEVEL	MISSION CRITICALITY	NEED DATE	STATUS
EVA ENCLOSURE & LIFE SUPPORT				
• EXTENDED LSS DURATION	L-M	H	96	R&D(P)
• RAPID CREW 'IN-SITU' SUIT SERVICING	L-M	H	96	R&D(P)
• PROTECTION AGAINST RADIATION HAZARDS	L	M-H	2000	R&D(P)
• RAPID EVA ACCESS - LSS COMPATIBILITY WITH S/C	L-M	H	96	R&D
• ENHANCED AUDIO/HEADS-UP DISPLAY & WRIST CUFF	L	M-H	95	R&D
EVA SUPPORT EQUIPMENT				
• SMALL LT-WT PORT. HYPERBARIC TREATMENT UNIT	L	H	2000	R&D
• SMALL LT-WT PORTABLE AIRLOCK	L-0	H	2000	STUDY
• SMALL LT-WT PORT. SURFACE TRANSPORTER	0	M-H	2005	STUDY
• SMALL LT-WT PORT. RAD/THERMAL/WIND SHELTER	0	H	2005	STUDY
• MULTI-PURPOSE EVA WORK STA. & MOTOR. FT RESTR.	L	H	95	R&D(P)
• CREW & EQUIP TRANSPORTER & POSITIONING AID	L	H	95	R&D(P)
• CREW & EQUIPMENT RECOVERY/RETRIEVAL UNIT	L	H	95	R&D(P)
• ADVANCED MANEUVERING UNIT	0	H	98	STUDY
• EMERGENCY SUIT 'LIFE JACKET'	0	M-H	2005	STUDY
• EMERGENCY EVA SURVIVAL GEAR	0	M-H	2000	STUDY
• SUIT CONTAMINATION DETECTION & CLEANING UNIT	L	H	95	R&D(P)
• DEBRIS/LOOSE EQUIP. HANDLING AIDS/STOW. UNITS	L-0	L-M	98	STUDY
• ADVANCED POWER TOOLS FOR EVA	L	M	98	R&D(P)
• PORTABLE EVA EXPER/SURVEY/SAMPLE KIT	0	L-M	2005	STUDY
• PORTABLE MULTI-PURPOSE EVA AVIONIC UNIT	0	M	2005	STUDY

KEY: L = LOW M = MODERATE H = HIGH | PARTIAL = P

IN-SPACE EXPERIMENTATION NEEDS/VOIDS

DEVELOPMENT FACTORS → DEVELOPMENT ELEMENTS	TECHNOLOGY STATUS/VOIDS
EVA ENCLOSURE & LIFE SUPPORT	
• RAPID EVA ACCESS-LSS COMPAT. WITH 14.7 PSIA CREW COMPT.	TECH IN WORK*
• RAPID CREW 'IN-SITU' SUIT SERVICING	TECH IN WORK*
• EXTENDED PERSONAL LIFE SUPPORT SYSTEM DURATION	TECH IN WORK*
• PROTECTION AGAINST RADIATION HAZARDS	TECH IN WORK*
• ENHANCED AUDIO/HEADS-UP DISPLAY & WRIST CUFF	TECH IN WORK
EVA SUPPORT EQUIPMENT	
• CREW & EQUIPMENT RECOVERY/RETRIEVAL UNIT	SOME NEW TECH NEEDED
• SUIT CONTAMINATION DETECTION & CLEANING UNIT	TECH VOID
• ADVANCED MANEUVERING UNIT	TECH BUILD-ON/NO ONGO
• MULTI-PURPOSE EVA WORK STA. & MOTORIZED FOOT RESTRAINT	SOME NEW TECH NEEDED
• CREW & EQUIP TRANSPORTER & POSITIONING AID	BREADBOARD-WK REQD
• SMALL LT-WT PORTABLE HYPERBARIC TREATMENT UNIT	TECH IN WORK*
• SMALL LT-WT PORTABLE AIRLOCK	NO ONGO WK+TECH VOID
• EMERGENCY SUIT 'LIFE JACKET'	NO ONGO WK+TECH VOID
• EMERGENCY EVA SURVIVAL GEAR	NO ON GOING WORK
• ADVANCED POWER TOOLS FOR EVA	SOME NEW TECH-WK REQ
• DEBRIS/LOOSE EQUIP. HANDLING AIDS/STOWAGE UNITS	NO SIG. ON GOING WORK
• SMALL LT-WT PORTABLE SURFACE TRANSPORTER-EVA CREW/EQUIP	MIN ON GOING WORK
• SMALL LT-WT PORTABLE RADIATION/THERMAL/WIND SHELTER	TECH VOID
• PORTABLE MULTI-PURPOSE AVIONIC UNIT	NO SIG ON GOING WORK
• PORTABLE EVA EXPER/SURVEY/SAMPLE KIT	NO ON GOING WORK

** TECH. IN WORK BUT NOT CONSIDERED FIRM FOR IMMEDIATE ELEMENT RDT&E GO-AHEAD*

IN-SPACE EXPERIMENTATION NEEDS

EVA ENCLOSURE & LIFE SUPPORT

- DEMONSTRATE RAPID SUIT DON & EV EGRESS IN 14.7 PSIA ENVIRONMENT
- DEMONSTRATE & VALIDATE 'AUTOMATED' & SHORT-TURN-AROUND ON-ORBIT SUIT SERVICING
- DEMONSTRATE EXTENDED SUIT LIFE SUPPORT SYSTEM DURATION & UTILITY BENEFITS
- DEMONSTRATE ALTERNATIVES IN 0-G AGAINST RADIATION HAZARDS
- DEMONSTRATE BASIC &/OR ALTERNATIVES TO AUDIO/DISPLAYED INFORMATION TO THE CREW

EVA SUPPORT EQUIPMENT

- DEMONSTRATE & VALIDATE ZERO/LOW-G CREW/EQUIPMENT RECOVERY/RETRIEVAL UNIT
- DEMONSTRATE CONTAMINATION ACQUISITION, VALIDATE SPECIES IDENT., & EVAL. REMOVAL TECHNIQUES
- DEMONSTRATE & VALIDATE ZERO/LOW-G ADVANCED MANEUVERING UNIT
- DEMONSTRATE & EXAMINE RANGE OF MULTI-PURPOSE EVA WORK STA. & MOTORIZED FOOT RESTRAINT
- DEMONSTRATE, EVAL. UTILITY/RANGE, & ASSESS PWR/UNPOWERED CREW/EQUIP XPORTER/POSITION AID
- DEMONSTRATE & VALIDATE SMALL LT-WEIGHT PORTABLE HYPERBARIC TREATMENT UNIT
- DEMONSTRATE & VALIDATE SMALL LT-WEIGHT PORTABLE AIRLOCK
- EXAMINE & ASSESS ALTERNATIVES FOR A SUIT 'LIFE JACKET'
- DEMONSTRATE & ASSESS CAPABILITY & UTILITY OF EVA SURVIVAL GEAR
- DEMONSTRATE & ASSESS EVA POWER TOOLS, E.G., CUTTERS, DRILLS, WELDERS, BONDERS, ETC.
- DEMONSTRATE & ASSESS UTILITY & SAFETY OF DEBRIS/LOOSE EQUIP. HANDLING AIDS/STOWAGE UNITS
- DEMONSTRATE & ASSESS UTILITY OF MULTI-TERRAIN SMALL LT-WT PORT. SURFACE TRANSPORTER
- DEMONSTRATE & ASSESS SET-UP/USE OF RAPID DEPLOY ZERO/LOW-G RAD/THERMAL/WIND SHELTER
- DEMONSTRATE UTILITY & VALIDATE PORTABLE MULTI-PURPOSE AVIONIC UNIT
- DEMONSTRATE UTILITY & FLEXIBILITY OF PORTABLE EVA EXPER/SURVEY/SAMPLE KIT

EVA TECHNOLOGY ELEMENTS - PRIORITIZATION

DEVELOPMENT ELEMENTS	PRIORITY
EVA ENCLOSURE & LIFE SUPPORT	
• RAPID EVA ACCESS-LSS COMPAT. WITH 14.7 PSIA CREW COMPT.	1
• RAPID CREW 'IN-SITU' SUIT SERVICING	2
• EXTENDED PERSONAL LIFE SUPPORT SYSTEM DURATION	3
• PROTECTION AGAINST RADIATION HAZARDS	4
• ENHANCED AUDIO/HEADS-UP DISPLAY & WRIST CUFF	5
EVA SUPPORT EQUIPMENT	
• CREW & EQUIPMENT RECOVERY/RETRIEVAL UNIT	1
• SUIT CONTAMINATION DETECTION & CLEANING UNIT	2
• ADVANCED MANEUVERING UNIT	3
• MULTI-PURPOSE EVA WORK STA. & MOTORIZED FOOT RESTRAINT	4
• CREW & EQUIP TRANSPORTER & POSITIONING AID	5
• SMALL LT-WT PORTABLE HYPERBARIC TREATMENT UNIT	6
• SMALL LT-WT PORTABLE AIRLOCK	7
• EMERGENCY SUIT 'LIFE JACKET'	8
• EMERGENY EVA SURVIVAL GEAR	9
• ADVANCED POWER TOOLS FOR EVA	10
• DEBRIS/LOOSE EQUIP. HANDLING AIDS/STOWAGE UNITS	11
• SMALL LT-WT PORTABLE SURFACE TRANSPORTER (EVA CREW/EQUIP)	12
• SMALL LT-WT PORTABLE RADIATION/THERMAL/WIND SHELTER	13
• PORTABLE MULTI-PURPOSE AVIONIC UNIT	14
• PORTABLE EVA EXPER/SURVEY/SAMPLE KIT	15

SUMMARY/CONCLUSIONS

SUMMARY

1. NASA & CANDIDATE DoD MANNED MISSIONS PRESENTED & TECHNOLOGY NEEDS RELATED TO EACH AND TO NASA 'MODEL' SCHEDULE
2. TECHNOLOGY NEEDS IDENTIFIED AND DEVELOPMENT FACTORS INDICATED
3. RATIONALE FOR EVA SYSTEM HDWR DEVELOPMENT PORTRAYED

CONCLUSIONS

1. TOTAL/ALL-UP SUIT TECHNOLOGY NOT YET IMMEDIATELY READY FOR FULL RDT&E PUSH
   - TECHNOLOGY IS BEING WORKED HARD AT NASA-JSC/AMES
2. MANY EVA EQUIP. ELEMENTS IN BRASSBOARD DEVELOPMENT STATE
3. CERTAIN EVA EQUIPMENT NOT BEING WORKED RELATIVE TO MISSIONS IMMEDIATELY BEYOND FREEDOM SPACE STATION ASSEMBLY
4. MANY STATION EVA ELEMENTS LEND THEMSELVES TO ORBITER PRECURSOR FLIGHTS
5. EVA TECHNOLOGY NEEDS A MORE VIGOROUS $ INFUSION TO ASSURE AVAILABILITY, VERIFICATION, AND MULTI-USER NEEDS/DATES
   - OPPORTUNITY FOR NASA & DoD MUTUAL INVESTMENT BENEFIT

EVA and Pressure Suit Technology

Prof. David L. Akin

Space Systems Laboratory

Massachusetts Institute of Technology

Background

- **Gemini**
  - Free-floating mobility
  - Experiment collection
  - Investigation of restraints
- **Apollo**
  - Self-contained life support equipment
  - Retrieval of mapping camera film
  - Lunar surface operations
  - Surface transport infrastructure
- **Skylab**
  - Planned servicing of instruments
  - Contingency repairs
- **Shuttle**
  - Satellite retrieval
  - ORU changeout
  - Dexterous repair operations
  - Initial EVA/robotic cooperation
  - Untethered MMU operations
  - Large object handling
  - Unpracticed EVA
  - Structural assembly

Research Needs

- Development and use of physiological workload measurement systems for neutral buoyancy simulation
- Correlation of physiological workloads between neutral buoyancy and flight
- Calibration of forces required internally to actuate suit joints
- Development of noninvasive neuromuscular instrumentation for quantifying fatigue in critical muscle groups (wrist and hands)
- Development of advanced computer models of EVA with correlation of force, kinematic, dynamic, and workload elements in neutral buoyancy and space flight
- Development of rule-based system for predicting EVA task performance for use as a simplified front-end to "CAD Astronaut" model

Technology Needs

- Gloves with better mobility, dexterity, tactility
- Simplified suit systems for on-site maintenance and refurbishment, extended operational lifetime
- Non-venting cooling system, zone heating and cooling
- Advanced controls and displays, particularly video
- Extended set of available hand and power tools
- Non-intrusive body joint position and force sensors for biomechanics data collection
- Maneuvering units with additional ΔV, single-hand control, and autonomous navigational capability (leading up to astronaut support vehicle/EVA Retriever)
- In-space suit decontamination systems, particularly for hydrazine

In-Space Experimentation Needs

- Conduct routine EVAs to build experience base and to allow for experimental opportunities
- Baseline the use of suits instrumented for biomechanics and workload measurements to expand quantitative data base on EVA operations
- Conduct a series of fiduciary experiments to determine the limits of human capability in EVA, with and without the use of EVA tools/aids/support systems
- Assess the use of AI technology to provide suit monitoring and error diagnosis, reducing or eliminating the need for mission control monitoring
- As telerobotic systems develop, investigate cooperative roles for EVA and robotics to enhance space operations

In-Space Experimentation Needs (cont.)

- Evolve life support systems towards regenerative technology to allow for extended operations in space or on planetary surfaces
- Assess the use of bidirectional video for reducing crew training requirements
- Investigate the use of telepresence technology to replace neutral buoyancy training for long-duration space crew
- Develop "CAD Astronaut" to allow long-duration space crew to investigate trade-offs in EVA techniques, simplify EVA planning and training, reduce dependence on mission control
- Experimentally verify research applied to innovative high-payoff concepts, such as skinsuit technology

8.2 HUMAN PERFORMANCE

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CREW AND ENVIRONMENTAL FACTORS

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Crew Research and Space Human Factors

INTRODUCTION/BACKGROUND GOALS

- "To develop empirically-based scientific principles that identify the environmental, individual, group, and organizational requirements for long-term occupancy of space by humans."

  — Report of the National Research Council Committee on Space Biology and Medicine ("The Goldberg Report"), p. 169

- To develop useful and practical approaches to selecting, training, and organizing effective crews for long duration space missions in collaboration with operational organizations.

- To provide a scientific resource to organizations responsible for man-systems design, crew selection and training and missions operations.

TECHNOLOGY NEEDS

Critical shortage of relevant research.
No operational guidelines for spaceflight or long-term space occupancy.

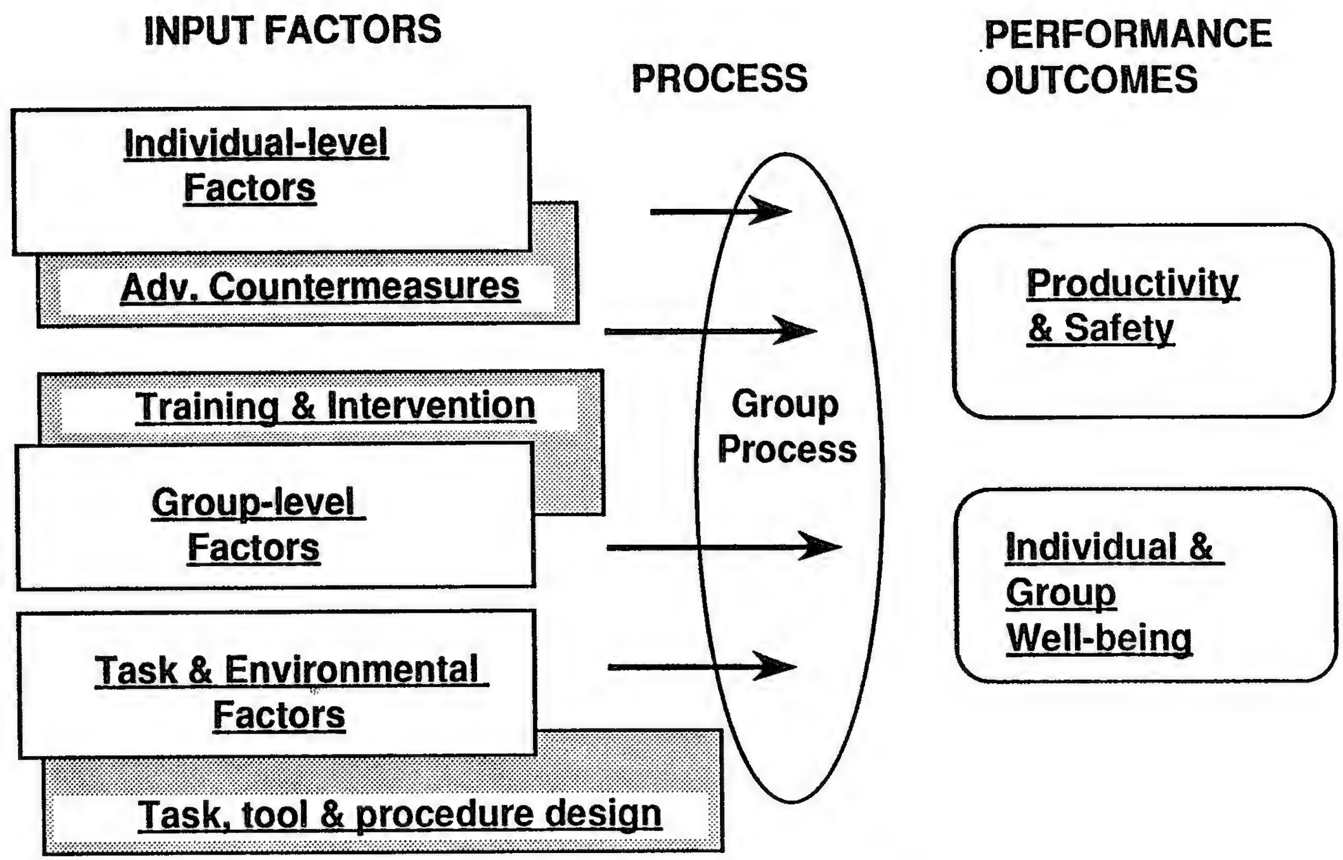
PROBLEM AREAS

1. Individual and Physiological
2. Crew and Interpersonal
3. Organization and Management
4. Training and Intervention
5. Environmental and Task

HUMANS IN SPACE	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	HUMAN PERFORMANCE

TECHNOLOGY NEEDS

Research for Optimizing Human Performance



CONCEPTUAL FRAMEWORK

adapted from McGrath, 1984

IN-SPACE EXPERIMENTATION NEEDS/VOIDS

Multi-phase Research Plan

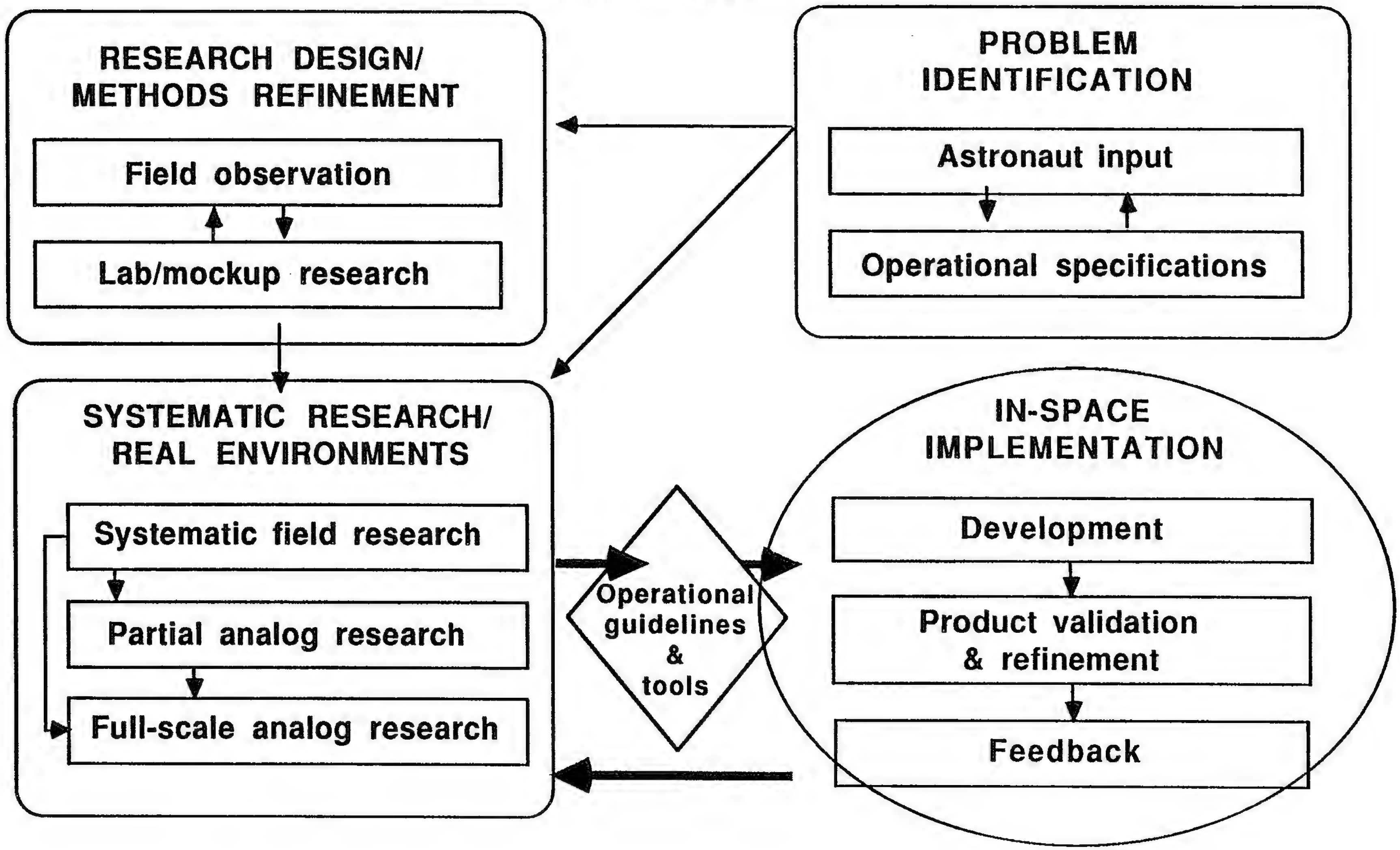
- Laboratory/Mockup Research
- Field Observation
- Systematic Field Research
- Partial Analog Research
- Full-Scale Analog Research

Relevant Analogous Environments

- Space Vehicle Analog
- Space Station Analog
- Planetary Exploration Analog
- Astronaut/Mission Control
  Telescience Analog

IN-SPACE EXPERIMENTATION NEEDS/VOIDS

An Integrated Approach



ARTIFICIAL GRAVITY

Larry G. Lemke
NASA, Ames Research Center

INTRODUCTION/BACKGROUND

- ..."THERE APPEARS TO BE A GENERAL PERCEPTION THAT THE ABSENCE OF LIFE-THREATENING MEDICAL PROBLEMS IN THE MANNED SPACE PROGRAM IMPLIES THAT THERE IS LITTLE NEED TO BE CONCERNED ABOUT HEALTH-RELATED ISSUES ON A MANNED SPACE STATION OR IN INTERPLANETARY MISSIONS OF SEVERAL YEARS DURATION. *BASED ON WHAT WE KNOW TODAY, THIS ASSUMPTION OF CONTINUED SUCCESS CANNOT BE RIGOROUSLY DEFENDED*".

--NATIONAL RESEARCH COUNCIL, COMMITTEE ON SPACE BIOLOGY & MEDICINE, 1987--

- "LONG-DURATION HUMAN HABITATION OF THE MOON AND MARS WILL REQUIRE PRIOR LONG-TERM STUDIES OF THE EFFECTS OF EXPOSURE TO 1/6 AND 1/3 G ON ANIMALS AND, EVENTUALLY HUMANS, INCLUDING STUDIES OF MULTIGENERATIONAL EXPOSURE TO VARIED G LEVELS"

•RECOMMENDATION:

A TETHERED (> 10-METER DIAMETER) VARIABLE GRAVITY RESEARCH FACILITY FOR THE SPACE STATION THAT WOULD GREATLY REDUCE CORIOLIS/GRADIENT PROBLEMS ACROSS LARGE ANIMALS AND THAT WOULD BE OPERATIONAL BEFORE THE START OF ANY HUMAN SPACE MISSIONS OF EXTENDED DURATION"

--ROBBINS COMMITTEE REPORT, 1988--

MISSION APPLICATIONS

PROBABLE:

- HUMAN MARS EXPLORATION SCENARIOS

POSSIBLE:

- LUNAR BASES
- ADVANCED SPACE STATIONS
- HUMAN ASTEROID RECONNAISANCE

TECHNOLOGY NEEDS

- DESIGN STRATEGIES, CONTROL ALGORITHMS, & SPECIALIZED ACTUATORS TO ALLOW RELIABLE & SAFE CONTROL OF SPINNING, TETHERED DUMBBELL CONFIGURATIONS

STRATEGIES,:
- OPTIMAL MASS DISTRIBUTION
- OPTIMAL ACTUATOR PLACEMENT
- OPTIMAL ACTUATOR TYPE

ALGORITHMS,:
- END-BODY ATTITUDE CONTROL
- END-BODY PROPULSIVE THRUSTING CONTROL
- TETHER VIBRATION CONTROL
- TETHER LENGTH CONTROL

ACTUATORS:
- END-BODY ATTITUDE CONTROL
- TETHER LENGTH CONTROL

IN-SPACE EXPERIMENTATION NEEDS

EXPERIMENT HARDWARE:

- SMALL, (~ 1000KG) FREE-FLYING, REMOTELY CONTROLLED, TETHER-CONNECTED DUMBBELL SPACECRAFT
- INSTRUMENTED TO MEASURE ALL IMPORTANT STATE VARIABLES
- ABILITY TO CONTROL SAME DEGREES-OF-FREEDOM AS HUMAN-RATED SPACECRAFT
- ROTATIONAL AND VIBRATIONAL EIGENVALUES CHOSEN FOR DYNAMIC SIMILARITY(TO ALLOW SCALING TO FULL-SIZE FACILITY)

EXPERIMENT OBJECTIVES:

- MAINTAIN STEADY-STATE HABITAT G-LEVEL WITHIN +/- 1%, 3-AXIS ATTITUDE WITHIN +/- 1 DEG.
- STABILIZE COUPLED TRANSLATIONAL, ROTATIONAL, AND VIBRATIONAL MODES DURING SPIN-UP, SPIN-DOWN, TRANSLATIONAL THRUSTER FIRINGS
- CONTROL TRANSLATIONAL DELTA-V WHILE SPINNING TO < 1 m/s (INCLUDING PLANE CHANGES)
- DEMONSTRATE RECOVERY FROM FAILURES

HUMANS IN SPACE	IN-SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6-9, 1988	HUMAN PERFORMANCE

SUMMARY/RECOMMENDATIONS

- HUMAN EXPLORATION MISSIONS MAY REQUIRE ARTIFICIAL GRAVITY
- VERY LARGE RADIUS ($\approx$ 225 m) CENTRIFUGE SEEMS MOST CONSERVATIVE FROM BIOLOGICAL PERSPECTIVE, MOST CHALLENGING FROM TECHNOLOGICAL PERSPECTIVE
- CONTROL OF LARGE, HIGHLY FLEXIBLE, ROTATING SYSTEMS MUST BE SHOWN SAFE AND RELIABLE PRIOR TO HUMAN-RATING
- EXPERIMENT OBJECTIVES CAN BE ACHIEVED WITH SUB-SCALE, FREE-FLYING DUMBBELL CONFIGURATION:
- INITIATE FLIGHT EXPERIMENT DEFINITION AND DEVELOPMENT SOON TO BE CONSISTENT WITH OVERALL AGENCY SCHEDULE
  - LABORATORY RESEARCH, SIMULATION, & ANALYSIS
  - CONCEPTUAL DEVELOPMENT OF FLIGHT HARDWARE

HUMAN PERFORMANCE

William R. Ferrell

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University of Arizona
Tucson, Arizona

INTRODUCTION / BACKGROUND

HUMAN PERFORMANCE : Human characteristics that affect the design of tasks, human-system interfaces, training

NASA SUCCESS IN DESIGN FOR HUMAN PERFORMANCE
- Humans in space
- Ground control of remote operations

ROLES OF HUMANS IN SPACE WILL CONTINUE TO CHANGE
- Passenger to Experimenter to Scientist / Engineer
- Passive to Active
- Sensory - motor skills to Decision - making / Problem - solving

CURRENT BASES FOR DESIGN - will have to evolve
- NASA & Contractor experience
- Data & standards compilations, e.g. MSIS & MSRB
- Models for dynamic manual control
- Models for routine cognitive skills, motor skills, sensory function
- Simulation methods for crew activity and work load analysis
- Guidelines for computer - human interface design
- Beginnings of useful models for cognitive performance of specific tasks, e.g., debugging, transfer of procedural training

HUMAN FACTORS FIELD
- Uneven development and too little basic research
- Focus on skills, task components

MISSION APPLICATIONS

- Multi-way, interpersonal communication with voice, text and images
- High - dexterity manipulation
- Monitoring of intelligent monitoring systems
- Skill maintenance and training
- Data interpretation and analysis
- Information retrieval, storage and management tasks
- Intervention in and redirection of experiments
- Participation in revising old and devising new experiments
- Equipment repair
- Cooperative, creative problem solving and strategic decision making

TECHNOLOGY NEEDS

COMPUTER - BASED, INTELLIGENT SUPPORT FOR :

- Problem solving and diagnosis
- Decision making
- Information management
- Monitoring of systems and environments
- Skill maintenance and learning
- Cooperative work with voice, text and images

ENABLING TECHNOLOGIES:

- Dynamic management of multi-media, multi-channel computer-human communication
- Language (and spoken language) understanding systems
- Intention inference
- Image and geometry understanding systems

DESIGN TECHNOLOGIES:

- Task analysis and simulation
- Rapid prototyping
- Integrated human performance models incorporating responses to the space environment

IN - SPACE EXPERIMENTS NEEDS / VOIDS

Most of the technology for supporting human performance in space can be developed and tested without in-space experimentation.

In-space experimentation is important for:

- **Design technologies, to determine / verify space environment effects on performance**
- **Specific interface design proposals, to assess interactions among task, interface, habitat, work-station and crew characteristics in the space environment -- early in the design process.**

Need to begin early to develop the research base for design of effective support for distinctively human role in space.

SUMMARY / RECOMMENDATIONS

ROLES: Science, Monitoring, Diagnosis, Intervention, Repair

NEED KNOWLEDGE-BASED TECHNOLOGIES to support:
- Creative Problem Solving
- Unforseen Activities
- Intervention and Repair
- Cooperative Planning & Decision

SUBSTANTIAL SUPPORT FOR GROUND - BASED RESEARCH IS NEEDED TO DEVELOP THESE TECHNOLOGIES

IN - SPACE EXPERIMENTATION:
- Physiological / Perceptual / Anthropometric modeling
- [Habitat & EVA experiments] (related sub - themes)
- [TELEOPERATION experiments]
- Multi - operator, cooperative workstations
- Task / Interface simulations for testing interactions in context and for timely design feedback

NEED FOR AN IN-SPACE FACILITY TO SUPPORT DESIGN

CRITICAL ISSUES:
- Intelligent , dynamic interface management systems
- System integration -- a technical not a management--problem

8.3 CLOSED-LOOP LIFE SUPPORT SYSTEMS

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Physical/Chemical Closed Loop Life Support

R.D. MacElroy
NASA / Ames Research Center

Background. . .

Closed-loop Life Support Focuses:

- Post-Space Station Life Support issues
- Efficient regeneration of life support materials
- Further development of existing technologies
- Promotion of innovative technologies
- Evaluation of new technologies

Technology Needs

Life Support Functions / Technologies:

- Collection of CO_2; adsorber regeneration
- Separation of gases
- Generation of O_2 from H_2O, CO_2
- Management and processing waste streams
- Purification of reclaimable water
- Process, sub-system and system sensing, monitoring and control
- Thermal control

In-Space Experimentation Needs:

* Subsystems will be specifically designed to reduce reliance on gravity and low radiation levels
  - However, testing in the space environment will be essential because of long-term human reliance on life support devices
  - Physical integration of subsystem will be simulated; however, validation and verification of in-space behavior is required
  - Start-up, shut-down and operational transients must be evaluated in the space environment

In-space Experimentation needs:

* A central issue: gas - liquid separation
* Related issues:
  - liquid behavior on surfaces in low gravity
  - changes in thermal behavior caused by differences in the convective behavior of fluids
* In general, subsystem designs that rely on forced fluid movements will obviate effects caused by decreased gravity

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CLOSED LOOP LIFE SUPPORT

INDUSTRY PRESENTATION

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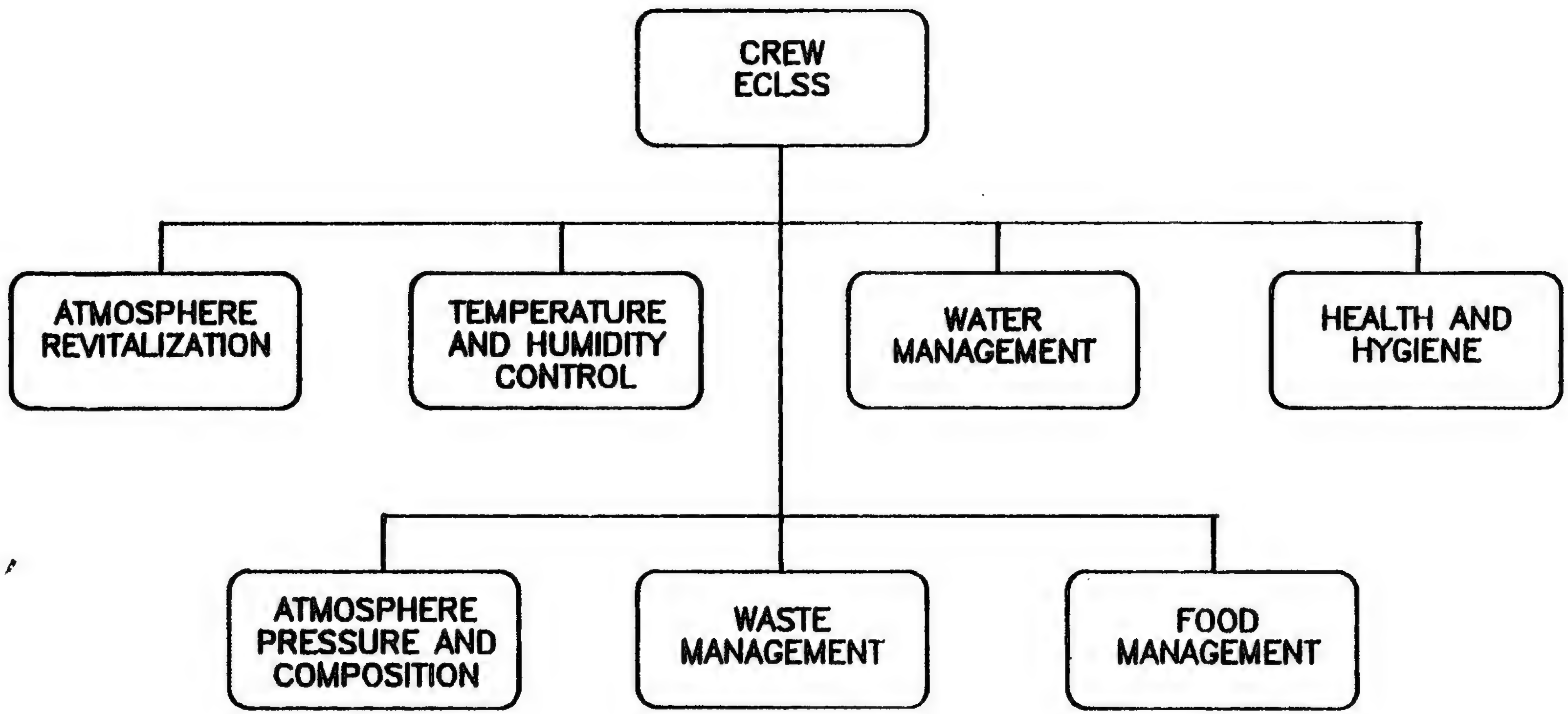
SYSTEMS TESTS LESSONS LEARNED/ISSUES

- MATERIALS SELECTION/COMPATIBILITY
- CAREFUL DESIGN OF SYSTEM CLOSURE
- INTEGRATION OF SUBSYSTEMS
- ON—BOARD MAINTENANCE AND SERVICING

HUMANS IN SPACE	IN–SPACE TECHNOLOGY EXPERIMENTS WORKSHOP DECEMBER 6–9, 1988	CLOSED LOOP LIFE SUPPORT

TECHNOLOGY NEEDS

LIFE SUPPORT FUNCTIONS



LIFE SUPPORT TECHNOLOGY SELECTION DRIVERS

- OPERATING ENVIRONMENT
  - Gravity fields
  - Ambient pressures
- RELIABILITY/MAINTAINABILITY
- SAFETY
- POWER, MASS, VOLUME
- DEVELOPMENT COST AND SCHEDULE
- RESTRICTIONS ON RESUPPLY, EXPENDABLES, DISCHARGES

IN-SPACE EXPERIMENTATION NEEDS/VOIDS

PHYSICAL-CHEMICAL LIFE SUPPORT TECHNOLOGY

FUNCTION	TECHNOLOGY AREA	NEED
WATER RECLAIMATION	• Liq/Air Separation	• Passive Separation Devices
	• Solids Separation	• Filter Solids Accumulation
	• Fluid Transport	• Wicking Devices
WASTE MANAGEMENT	• Pre-Treatment	• Effectiveness of Antifoam in 0 g
	• Solids Reduction	• Low Temp/Energy Processes
AIR REVITALIZATION	• Catalytic Reactors	• Mixing & Heat Dissipation
		• Behavior of light gases & thermal gradients
		• Behavior of flames & plasmas
	• Electrochemical Cells	• Change in efficiency

CONTROLLED ECOLOGICAL/BIOREGENERATIVE LIFE SUPPORT TECHNOLOGY

FUNCTION	TECHNOLOGY AREA	NEED
FOOD, OXYGEN, & WATER PROD.	• Lighting	• Sun light collection, filtering, and distribution from orbiting platform
	• Nutrients	• Nutrient solution delivery
	• Plant Growth	• Incremental Introduction of plants on Space Station program
FOOD PROCESSING	• Conversion	• Glycerol & protein extraction • Biological conversion processes
WASTE PROCESSING	• Bioregeneration	• Biodigestion in 0 g • Gas/liquid/solid separation
AUTOMATION & CONTROL	• Instrumentation Design	• Gravity independent sensor dev. • Struct dsn (minimize dead spaces)

PHYSICAL/CHEMICAL CLOSED-LOOP LIFE SUPPORT

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INTRODUCTION/BACKGROUND

LIFE SUPPORT RESUPPLY REQUIREMENTS SERIOUSLY CONSTRAIN MANNED SPACE MISSIONS.

CURRENT TECHNOLOGIES

* PROVIDE FOR LITTLE RE-USE
* ARE COSTLY
* INHIBIT SPACE MISSION FLEXIBILITY
* ARE NOT WELL-DEVELOPED
* HAVE TECHNICAL AND SAFETY DRAWBACKS

TECHNOLOGY NEEDS

ORBITAL/TRANSIT NEEDS

- REDUCED WEIGHT, POWER AND HEAT
- EFFICIENCY
- SAFETY
- MICROGRAVITY-EFFECTIVE SUBSYSTEMS
- INTEGRATION

TECHNOLOGY NEEDS

SURFACE NEEDS

* TRANSPORTATION
* SURFACE RESOURCE USE
* AUTONOMY AND RELIABILITY
* PRODUCT MANAGEMENT
* POWER

IN-SPACE EXPERIMENTATION NEEDS

ORBITAL/TRANSIT NEEDS

* FLUID SUBSYSTEM TESTS
* MASS VS. CONTAINMENT TRADES
* MICROGRAVITY SENSORS AND CONTROL
* SURFACE/CATALYTIC EFFICIENCIES
* RELIABILITY
* POWER AND HEAT REDUCTIONS

IN-SPACE EXPERIMENTATION NEEDS

SURFACE NEEDS

* ON-SITE RESOURCE USES/TESTS
* LONG-TERM AUTONOMY AND RELIABILITY
* TRANSPORT AND DEPLOYMENT TESTS
* PRODUCT STORAGE, DISTRIBUTION AND USE
* POWER

HUMANS IN SPACE
CRITICAL TECHNOLOGY REQUIREMENTS

REMUS BRETOI
AMES RESEARCH CENTER

EVA / SUIT

- DEVELOP THE TECHNOLOGY FOR MEASUREMENT OF EVA FORCES, MOMENTS, DYNAMICS, PHYSIOLOGICAL WORKLOAD, THERMAL LOADS AND MUSCULAR FATIGUE.
- EVALUATE COOPERATIVE ROLES BETWEEN EVA AND TELEROBOTS AND FOR IVA AND ROBOTICS.
- SUIT CONTAMINANTS DETECTION, IDENTIFICATION AND REMOVAL.

HUMAN PERFORMANCE

- TECHNOLOGY FOR MEASUREMENT OF GRAVITY-RELATED ADAPTATION AND RE-ADAPTATION BEHAVIOR

- TECHNOLOGY FOR IN-SPACE ANTHROPOMETRIC AND PERFORMANCE MEASUREMENT

- VARIABLE - GRAVITY FACILITY AND APPLICATION TECHNOLOGY

CLOSED LOOP LIFE SUPPORT SYSTEMS

- IMPROVED PHASE SEPARATION SYSTEMS
- GRAVITY-INDEPENDENT SENSOR SYSTEMS
- WASTE-CONVERSION PROCESSES
- FLUID MIXING AND COMPOSITION CONTROL
- REACTOR PHENOMENA
- CHEMICAL SPECIES SEPARATION

OTHERS TO CONSIDER - POSSIBLY BY OTHER THEMES

- FIRE AND SMOKE DETECTION SYSTEM
- ZERO-G PHASE CHANGE PHENOMENA FOR EVA THERMAL MANAGEMENT
- FOAMING COUNTERMEASURES